Biogeography of northeast Tasmania

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INTRODUCTION

The papers published in this volume, on the theme of the biogeography of northeast Tasmania, were presented at a symposium held under the auspices of the Queen Victoria Museum and Art Gallery over the three days 4-6 February, 1995. The symposium was organised as a tribute to the late Mr Brian Plomley, in recognition of the significant contribution he made towards the increase in our knowledge of both the natural as well as cultural history of the State of Tasmania. Biographical information about Mr Plomley, compiled for a display at the symposium, is reproduced here.

Northeast Tasmania was defined for the symposium as the area to the east of a line drawn from George Town, along the River Tamar, to Evandale; and north of a line from Evandale to Ironhouse Point, near St Marys on the east coast. Due to a variety of factors, but perhaps predominantly a consequence of its distance from Hobart, the area has in the past received relatively little attention from earth, plant and animal scientists employed by State Government departments or by the University. In a conscious attempt to compensate for this, staff and associates of the Queen Victoria Museum and Art Gallery, notably the Director, Mr Chris Tassell, and Honorary Associates Mr Brian Plomley and Mrs Mary Cameron, have done a great deal to promote biogeographic research in the area. Much of this research has been, and continues to be, funded by the Plomley Foundation. Although due to our proximity to the area our own efforts will no doubt continue to be concentrated here, it is perhaps time for the region to be given greater focus by other workers. The (perhaps over-ambitious) aim of the symposium was to review the state of our knowledge of the defined region, and hence to identify places or features having special interest or importance. Simultaneously it would identify significant gaps in this knowledge. I hope that the information drawn together at the symposium, and now recorded in this volume, will provide a valuable resource on the study area for some years to come. What a welcome outcome it would be if this volume stimulated so much additional research that it rapidly became outdated!

In my capacity of convenor of the symposium I wish to acknowledge the support and assistance of all those who contributed to the success of the meeting.

Ms Louise McGowan managed the logistical aspects of the symposium, notably travel, etc. for delegates, the bus tour and social programmes and collation of abstracts, allowing my own focus to be concentrated on the scientific programme. Ms Jane Griffith and Mrs Judy Rainbird performed a magnificent job in keeping the Museum's zoology function running smoothly while two of us were 'on loan' to the symposium. The assistance of Museum volunteer Mr Daniel Soccol must not go unrecognised.

It is a heart-warming reflection of the high level of commitment to their disciplines that all but one of the thirty speakers originally invited to present review papers at the symposium accepted that invitation. The one exception was reasonably excused on the basis that he was to be working overseas at the time of the meeting! Considerable assistance in planning the scientific programme was provided by Mr Chris Tassell, Dr Bob Mesibov and Mr Fred Duncan.

The meeting was opened by the Hon. John Beswick, Deputy Premier of Tasmania and Minister for Education and the Arts and, significantly, a member of Parliament whose electorate includes the focus area of the symposium.

The meeting was predominantly a scientific one, as will be seen from the content of the majority of the papers. However, in addition to the scientific programme, an evening forum was held, not requiring symposium registration, on the wider topic of land management in northeast Tasmania. Presentations by speakers at the forum varied (appropriately) in the proportion of factual, as opposed to experiential or pictorial, content. Dr Mick Brown set the biogeographic significance of northeast Tasmania in a wider context, Mr Stan Matuszek spoke on wildlife conservation, Mr Brian Farmer discussed forestry and Mr Ian Farquhar spoke of his farming experience in the region. The discussion was facilitated by the late Mr Paul Strong.

The contents of the paper by Mark Neyland and Michael Askey-Doran in this volume overlap extensively with one already published by these authors in *Fire and Biodiversity: The Effects and Effectiveness of Fire Management*, published as Biodiversity Series, paper no. 8 by the Department of Environment, Sport and Territories, Canberra, in 1996. We thank the Department for permission to republish this valuable contribution.

The formidable task of rounding up the papers and shaping them to fit this volume was undertaken by an editorial team led by Dr Bob Mesibov with assistance from Dr Brian Smith and Ms Kaye Dimmack.

Finally, it is a special pleasure to acknowledge the personal interest taken in the symposium, on behalf both of the Plomley family and the Plomley Foundation, by Ms Jenner Plomley. The trustees of the Plomley Foundation are thanked for making financial assistance available for the production of this volume.

Dr Tim Kingston
Convenor

N.J.B. (Brian) Plomley, A.M., M.Sc. 1912-1994

Brian Plomley gained his Bachelor of Science degree from the University of Sydney in 1935 and his Master of Science degree from the University of Tasmania in 1946. In the same year he was appointed Director of the Queen Victoria Museum, Launceston, a position he held until 1950. From 1950 to 1960 he was a Senior Lecturer in the Department of Anatomy, University of Sydney; from 1961 to 1965 a Senior Lecturer in the Department of Anatomy, University of New South Wales; from 1966 to 1973 a Senior Lecturer and tutor in the Department of Anatomy and Embryology at the University College, London, (University of London); from 1974 to 1976 Senior Associate in Aboriginal and Oceanic Ethnology in the Department of History at the University of Melbourne.

He retired in 1977 but continued to work as an Honorary Research Associate at the Queen Victoria Museum and Art Gallery, Launceston. From 1966 to 1994 he published various scientific papers in periodicals, largely on biological topics; a manual for dissection for students of dentistry; a family history and seven major books on Tasmanian Aboriginals. These publications were all, of necessity, a product of part-time research, undertaken at his own expense when time and circumstances permitted.

Following retirement, Brian Plomley devoted almost all his time and efforts to further researching Tasmania's Aboriginal history, producing three more voluminous works on early exploration and Aboriginal people. His work is monumental and the excellence of his contributions to the published history of Tasmania rank him one of the quiet achievers of our time.

Brian Plomley died peacefully at Launceston on 8 April 1994.

Plomley Foundation
Queen Victoria Museum and Art Gallery

In September 1984 the Plomley Foundation was established with the generous support of Brian Plomley. The Foundation's aims in general were to encourage research and publication about Tasmania's natural and cultural heritage and to further develop the collections of the Queen Victoria Museum and Art Gallery. The Foundation consists of three major components: endowment funds, an art collection and a book collection, including a most important and extensive library concerned with Tasmanian history and in particular with the Tasmanian Aborigines.

Major themes have included early Tertiary floras, ecology of northeast coastal communities, both wetland and heaths, botanical surveys of Ben Lomond and Mt Barrow, as well as a study of Tasmanian inventions and innovations.

Results of studies funded by the Plomley Foundation have been published in the Queen Victoria Museum and Art Gallery's Occasional Paper and Technical Report series.

The Northeast in Its Context

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Abstract

Although the boundaries vary between authors the Northeast is recognized as a distinct natural region of Tasmania. This distinctiveness largely lies in its surface geology, its environmental domains, the relatively low degree of Tasmanian endemism in its biota, its wet eucalypt forest and heath plant communities, its biotic affinities to southeast mainland Australia and the absences of many species found to both the north and south of the region. Part of the explanation of its biotic distinctiveness may lie in the high degree of environmental change that occurred in the area as a result of the glacial-interglacial cycles of the Quaternary. The drying of Bass Strait during glacial times may have had particular significance. The region has many areas of outstanding significance for their natural values that are yet to gain secure reservation.

Introduction

The Northeast is popularly perceived as a distinct region of Tasmania. It has also been more formally recognized by the Tasmanian Department of Agriculture (Pinkard 1980) the Tasmanian Herbarium (Orchard 1988) and the Working Group for Forest Conservation (Hickey & Brown 1989). The boundaries of the Northeast differ between the land systems study (Pinkard 1980) and the nature conservation regionalisations (Orchard 1988, Hickey & Brown 1989), with the latter also dividing the Northeast into lowlands and highlands (fig. 1). It is the nature of regions that their cores are more easily recognized than their boundaries defined, as landscapes usually change gradually rather than abruptly, and different elements of the landscape do not necessarily have the same patterns of variation. Regions also suffer from the contiguity constraint. To ensure contiguity they almost always include areas that have greater similarity to areas outside the region than to other areas within it.

In the case of the Northeast there is unanimity that the coast forms one boundary. There is little agreement on the inland boundaries or the extent of coast included. However, in all of the formal regionalisations, the country to the east of the Tamar River estuary, the coast north of Falmouth and the mountains north and east of the South Esk River are included. Rather than addressing the somewhat futile question of the most appropriate boundary, in this paper I explore the distinctiveness of the northeast Tasmanian biophysical environment, both in its present state and as a product of Quaternary environmental change. From convenience rather than conviction I have taken the Northeast to have the boundaries of nature conservation regions 5 and 6 (Hickey & Brown 1989). My discussion centres largely on the physical environment and the biotic patterns evidenced by vascular plants, as the information base for these environmental elements is most complete on a statewide and national basis.

Fig. 1. The nature conservation regions of Tasmania (Hickey & Brown 1989) and the Northeast study area of Pinkard (1980). Nature conservation regions 5 and 6 are horizontally hatched and the study area of Pinkard (1980) is vertically hatched.

The physical environment

The region has a relatively small proportion of country underlain by dolerite, a rock of extreme rarity elsewhere on the Australian plate, but dominant in the landscape over most of east and central Tasmania. It also lacks the Precambrian rocks that make a large contribution to the distinctive nature of the west of Tasmania. Conversely, there are large areas of granitic rocks, uncommon

elsewhere in the State of Tasmania except for the Furneaux Group, but extremely common on the southeast Australian mainland. Broad coastal sand plains are more reminiscent of west Victoria and South and East Gippsland than of the rest of Tasmania. The sedimentary Mathinna Beds are largely confined to the Northeast within Tasmania. Granitic rocks, sand plains and Mathinna Beds cover more than three-quarters of the region, however defined.

Many of the most striking geomorphological features of the region are widespread in Tasmania. The dolerite plateaus and ridges that compose much of the highest country within the region, such as Ben Lomond and Mt Barrow, are widespread elsewhere in Tasmania, as are raised beach deposits (Murray-Wallace & Goede 1991), massive coastal parabolic dunes, dune-blocked wetlands and lunette lakes. However, the distinctive lithology of the granites and Mathinna Beds results in distinctive topographic and drainage patterns. One of the most interesting geomorphological features of the Northeast is the relict longitudinal dune system that striates much of the north coastal sand plain (Bowden 1983). Active longitudinal dunes are characteristic of the arid zone of Australia (Wasson et al. 1988). Relict dunes of this type are also found on Flinders Island and in the Northwest of the State, but attain their best development in the Northeast.

The climate of the coastal plains of the Northeast has some of the warmest summers experienced in Tasmania, the area sharing this distinction with the Midlands. In contrast, Ben Lomond experiences some of the coolest summers in Tasmania with mean daily temperatures in the warmest month below 10°C; it shares cool summers with other alpine areas of Tasmania. Mean annual precipitation lies within the Tasmanian extremes, varying from approximately 600 mm to between 1 800 and 2 000 mm. The seasonal distribution of rainfall varies from a distinct winter maximum in the west of the region to a more even distribution in the east. Overall, the climate of the Northeast is not particularly distinctive, having analogues elsewhere in Tasmania, as well as in southeast mainland Australia.

The hydrology of the streams of the Northeast is closely similar to that of other Tasmanian streams flowing into Bass Strait and many streams on the mainland (Hughes 1987). All the northeast Tasmanian streams included in the analysis of Hughes (1987) fell into her groups 1 and 4. The distinctively Tasmanian group was 3.

The distinctiveness of the physical environment of the Northeast within Tasmania can be tested by reference to the environmental domain analyses of Kirkpatrick and Brown (1991) and Lewis et al. (1991). The former used climatic, geologic and topographic variables to classify 10 x 10 km squares of the national mapping grid. The latter classified the physical environment of subcatchments using a similar range of variables (see also

M. Brown, this volume).

At the 12-group level in the classification of Kirkpatrick and Brown (1991) there were two domains that were concentrated in the Northeast and covered most of its area. One included most of the northeast Tasmanian highlands, with a small outlier of the domain in the upper Mersey River area. However, at the 68-group level there was no domain in common between these two areas. The other faithful and constant domain at the 12-group level covered most of the rest of the Northeast, but extended contiguously west and southwest to the approximate boundary of the Northeast used by Pinkard (1980), and occurred sporadically in the Furneaux Group. A coastal and island domain occurred more outside the Northeast than within it, and a southeast Tasmanian domain occurred in parts of the region's south and to the west of the highlands. However, these, and other sporadically occurring exotic domains, constituted only a small proportion of the area of the Northeast.

In the 30-group classification of Lewis et al. (1991) two domains again covered most of the Northeast, one covering most of the lowlands and the other most of the highlands. The highland domain had most of its area in the Northeast, but like the highland domain of Kirkpatrick and Brown (1991) had an outlier centred on the upper Mersey River. The lowland domain occurred extensively on King Island, the Furneaux Group and the extreme northwest of the State, with more of its area outside the Northeast than within it. Two domains of lesser extent were concentrated in the Northeast. One occupied the northern and eastern margins of the highlands, and the other occurred on the southern margin. Again, there were outliers of many other domains, but these constituted a small proportion of the total area.

There thus seems little doubt that the Northeast has a physical environment with an overall character that is different from that of other parts of Tasmania, and that this character has as much, if not more, in common with parts of the southeast Australian mainland than with the more characteristically 'Tasmanian' parts of Tasmania.

The biota

The Northeast lowlands have an extremely poor representation of Tasmanian endemic plants and animals. For example, most 10 x 10 km squares have only one or two Tasmanian endemic vascular plant species (Kirkpatrick & Brown 1984a). Only one Tasmanian endemic higher plant species, *Phebalium daviesii* (Lynch 1994, Lynch & Vaillancourt 1995), has its range contained within this area. No vertebrates are confined to the area in Tasmania, but there are several species of invertebrates that are both Tasmanian endemic and confined to the Northeast (e.g., see Mesibov, this volume; Smith, this volume).

The subalpine and alpine areas of the Northeast are richer

in Tasmanian endemic higher plants (Kirkpatrick 1982, Kirkpatrick & Brown 1984a). However, most of these occur extensively outside the region. The one high-mountain vascular plant species that is confined to the region in Tasmania, *Chionohebe ciliolata*, is widespread in New Zealand.

In contrast to its relative paucity of Tasmanian endemics the region has substantial numbers of vascular plant species that are rare in Tasmania. Some of these are confined to the Northeast within the island of Tasmania, being outliers of more extensive mainland populations. Such species include *Pultenaea mollis*, *P. hibbertioides*, *Villarsia exaltata*, *Allocasuarina paludosa* and *Cassinia longifolia*. There are also many plant and animal species that have their distributions concentrated in the region. These include the New Holland Mouse (see Hocking & Driessen, this volume), three species of reptiles (see Rounsevell et al., this volume), the Green and Gold Frog (see P. Brown, this volume), many plants and many invertebrates.

As a result of its relatively low Tasmanian endemism and relatively high incidence of southernmost populations, floristically and faunistically the Northeast forms one extreme of Tasmania. This can be seen clearly in the alpine floras (Kirkpatrick 1982, 1989). Ben Lomond is less similar in its alpine flora to Mt Counsel in the Southwest than to the Victorian and New South Wales mountains. Variation within plant species also shows the same southwest-northeast pattern. Well-documented examples include *Richea scoparia* (Menadue & Crowden 1983) and the *Eucalyptus gunnii-archeri* complex (Potts & Reid 1985).

The Northeast is the centre of distribution of many recognized vascular plant communities. However, most of the plant communities that occur in the Northeast are more widespread outside the region.

The following six of the 80 recognised Tasmanian wet eucalypt forest communities (Kirkpatrick, Peacock et al. 1988) are concentrated in the region: *Eucalyptus brookerana/E. obliqua-Bedfordia salicina* wet sclerophyll forest; *Eucalyptus dalrympleana-Pomaderris apetala-Bedfordia salicina* wet sclerophyll forest; *Eucalyptus dalrympleana-Tasmannia lanceolata-Dicksonia antarctica* wet sclerophyll forest; *Eucalyptus ovata-Acacia dealbata-Pomaderris apetala* wet sclerophyll forest; *Eucalyptus regnans/E. obliqua-Pomaderris apetala-Olearia lirata* wet sclerophyll forest; *Eucalyptus sieberi-Olearia argophylla-Coprosma quadrifida* wet sclerophyll forest. Many other wet eucalypt forest communities occur in the region.

Many of the 37 heath communities recognized by Kirkpatrick (1977) also have most of their distribution in the region. These are: *Danthonia-Bossiaea cinerea-Calytrix tetragona* heath; *Gompholobium huegelii-Epacris lanuginosa* heath; *Hibbertia sericea-Leucopogon*

virgatus heath; *Danthonia-Xanthosia pusilla-Helichrysum scorpioides* heath; *Bossiaea prostrata-Melaleuca gibbosa* heath; *Allocasuarina monilifera-Hibbertia acicularis-Brachyloma ciliatum* heath; *Poa gunnii-Melaleuca gibbosa-Centella cordifolia* heath; *Danthonia-Leucopogon parviflorus* heath; *Lepidosperma concavum-Gonocarpus tetragynus* heath. The region has a large proportion of Tasmanian heathy *Eucalyptus amygdalina* forest and most of Tasmanian *E. sieberi* forest (Duncan & Brown 1985; Kirkpatrick & Dickinson 1984).

Two of the 37 grassy communities recognized by Kirkpatrick, Gilfedder and Fensham (1988) are concentrated in the highlands of the Northeast. These are *Nothofagus cunninghamii-Oreomyrrhis* grassy shrubland and *Eucalyptus delegatensis-Agropyron pectinatum* grassy woodland. Grasslands and grassy woodlands are rare in the lowlands and contain no distinctively Northeast communities (Kirkpatrick, Gilfedder & Fensham 1988; McDougall & Kirkpatrick 1994). Of the 28 buttongrass moorland communities mapped by Jarman et al. (1988) only eastern sword sedgeland could be considered to be concentrated in the Northeast. Similarly, although the region contains more than half of the dry coastal communities mapped by Kirkpatrick and Harris (1995) only one, *Leucopogon parviflorus-Lepidosperma concavum-Oxalis perennans* heath, has the bulk of its distribution in the area. Although the region has more than its fair share of wetlands, none of the more common communities mapped by Kirkpatrick and Harwood (1983) have the bulk of their distribution in the area. There are no saltmarsh communities concentrated in the area (Kirkpatrick & Glasby 1981).

There are some substantial areas of rainforest in the highlands of the Northeast. However, none of the many rainforest communities recognized by Jarman et al. (1984, 1991) are centred on the Northeast. *Sphagnum* bogs are also widespread in the highlands, but, again, there are no distinctively Northeast communities (Whinam et al. 1989). The alpine floristic communities are similarly indistinctive (Kirkpatrick 1986a).

Thus, the vascular plant communities that most contribute to the differentiation of the Northeast from the rest of Tasmania are concentrated in wet eucalypt forest and heath.

Some of the more interesting features of the biogeography of the Northeast are absences of species that occur to both the north and south. The most striking example of this phenomenon is *Callitris rhomboidea*. This tree species is found widely in the Furneaux Group and in the coastal regions of southeast Tasmania, but is absent from the area between (Harris & Kirkpatrick 1991). Yet, the species has naturalized within the Northeast since European settlement (Harris & Kirkpatrick 1991). Other examples include *Hardenbergia violacea*, *Spyridium eriocephalum* and *Viminaria juncea*.

Eucalyptus globulus typifies a group that has a large distribution gap within the Northeast. It extends along the coast from southeast Tasmania as far as The Gardens and occurs in the Furneaux Group (Kirkpatrick 1975).

There is a large number of Tasmanian endemic vascular plant species that do not occur any further north than a line passing along the Fingal Valley through St Marys and Avoca from the coast to the Midlands. These include the eucalypts *Eucalyptus tenuiramis*, *E. pulchella*, *E. cordata* and *E. barberi*. This line appears to be a biogeographic divide as strong as the line that separates the quartzite high rainfall country of the Southwest from the more argillaceous and less perhumid east.

Quaternary environments and biotic patterns

The contemporary physical environment of the Northeast has been a rarity in the past, occurring only during the short interglacials that have punctuated the generally cold and dry conditions of the Quaternary. During most of the Quaternary sea levels did not even approximate those of today, with the coast near the edge of the continental shelf and Bass Strait replaced by dry land and lakes. The present sea level was attained only 6 500 years ago (Bowden 1983).

We have both direct and indirect evidence of the nature of the Northeast environment during the coldest periods of the Quaternary, when sea levels were very low. The most direct evidence comes from the work of Bowden (1983). From lee wave patterns in the longitudinal dunes he was able to deduce an 8 km/h decrease in mean westerly wind speed between the Last Glacial and the present. The formation of longitudinal dunes in itself implies less effective rainfall than is received today. Other evidence of much lower rainfall than today during the Last Glacial comes from Waterhouse Point where there is evidence of a vegetation type resembling the chenopodiaceous grasslands now found in the arid zone of Australia (Thomas 1991). Hope (1978) found evidence of a similar Last Glacial vegetation type from Hunter Island in the west of Bass Strait. It is interesting to note that there are many grassland species, such as *Glycine latrobeana*, still found in the Northeast, largely on argillaceous soils near the coast, as at Waterhouse Point and Petal Point. These may be relict from the more extensive grasslands which would have occurred on siliceous as well as argillaceous soils when evaporation greatly exceeded precipitation. Heathy vegetation on sand sheets gives way to grassy vegetation on this substrate where precipitation is at its lowest today (Fensham 1989).

Glacial depositional evidence elsewhere in the State has suggested that mean temperatures were approximately 6°C lower during the height of the Last Glacial than at present (Kiernan 1983). There is some evidence of colder Last Glacial conditions in the highlands of the Northeast in the form of deposits of frost-shattered rocks (Davies 1974, Caine 1983) and glacial landforms on Ben Lomond (see Sharples, this volume).

A decrease in mean temperatures of any magnitude has variable effects on temperature extremes in the context of a dramatic change in continentality. The present pattern of continentality in Tasmania can be almost totally explained using distance from the coast along a southwest-northeast vector in combination with distance from the nearest coast (Kirkpatrick & Fowler 1996). When this formula is applied to distances derived from the Last Glacial coast, and a reduction of mean temperature of 6°C is assumed, the eastern and southern part of the Northeast have average maximum summer temperatures that are much less than present than those in the northwestern section (fig. 2). The modelled average maximum summer temperature difference near Low Head was only approximately 1°C, whereas it was greater than 7°C in parts of the east and south of the region.

Summer temperatures and precipitation are critical in determining the limits of most Tasmanian plant species. Winter temperatures are of little broad-scale ecological significance, even in the high mountains, as the most intense frost events are largely confined to valleys. The dramatically lower precipitation over all the Northeast and the low summer temperatures that seem likely to have been experienced in all but the northwest of the area, contribute substantially towards an explanation of many of the biotic patterns described above.
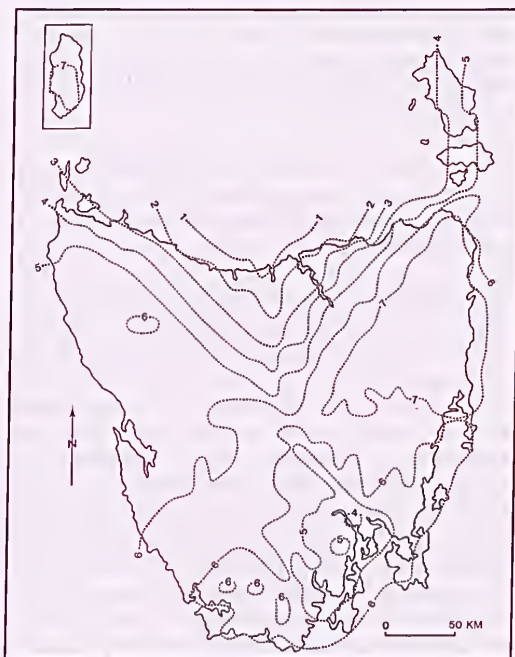

Fig. 2. The difference between mean summer daily maximum temperatures today and at the height of the Last Glacial, assuming a difference in sea surface temperatures of 6°C (see Kirkpatrick & Fowler 1996 for methods used to derive the data).

The chances of survival and re-immigration of temperature-sensitive plant species would have been greater in the continental area around Hobart or on Flinders Island, or where the continental shelf was narrow and temperature drop moderate, as at Great Oyster Bay, than in the Northeast. Further screening of species would have taken place on the coastal plain, which not only would have had very low rainfall but also lacks the topographic variation of most of Tasmania, including the Furneaux Group. Rugged topography increases the chances of survival of moisture-loving plants, as there are substantial differences in available moisture between north and south-facing slopes in Tasmania (Kirkpatrick & Nunez 1980). This phenomenon can be seen in the distribution of so-called relict rainforest in east Tasmania (Neyland 1991). The pattern of difference in summer temperatures and topography may also explain the survival of the centre of local endemism centred on the Asbestos Range (Kirkpatrick & Brown 1984b), and the higher number of Tasmanian endemics in the hills to the east of the Tamar River estuary than elsewhere in the lowlands of the Northeast (Kirkpatrick & Brown 1984a).

Noble (1986) has suggested that a positive deviation from expected values of the observed number of woody endemic species in the more northern alpine areas of the Northeast could be due to relative dryness during the Last Glacial, in contrast to their relative wetness now. There is a reasonable argument that precipitation may have been much less compared to the present in the north than the south of the Northeast, as the precipitation derived from evaporation off Bass Strait might be received preferentially in the north. Whatever the validity of this supposition, the analysis of Noble was basically flawed, as it did not take into account altitude and substrate influences on the number of woody endemics.

The Fingal Valley biogeographic divide lies almost in the centre of the eastern lobe of the area of maximum summer temperature change (fig. 2). The area of maximum temperature changes extends southwest-northeast from north of Port Davey to St Helens in present-day Tasmania, separating the areas of lesser change and forming a putative barrier to migration between them during glacial times. Although the Fingal Valley divide may be partly a function of the time needed for species to expand their ranges from refugia, it also marks the break between country largely underlain by dolerite and that largely underlain by granite and Mathinna Beds and is an obstacle to migration in itself, with lower rainfall and higher temperatures than the hills to the north and south.

Discussion

There is no doubt that the Northeast has physical environmental and biotic characters that render it a region worthy of recognition in the late Holocene. During the late Pleistocene it seems unlikely that the Northeast of today would be so readily perceptible, as the region seems to have experienced more massive environmental change

than most parts of Tasmania as a consequence of the disappearance of Bass Strait.

A large part of the highlands of the region of today would almost certainly have been covered with alpine vegetation (Kirkpatrick 1986b, Kirkpatrick & Fowler 1996). Forest species may have been confined to valleys in the foothills, and the banks of rivers. Some, such as *Nothofagus cunninghamii*, may have survived as alpine shrubs. It seems unlikely that wet eucalypt forest and heath species would have disappeared from the region, given the diversity and distinctiveness of the communities that they compose today. However, there is no reason to believe that the same communities we find today were present in the past.

Palynological evidence and the presence of grassy woodland and grassland species such as *Eucalyptus pauciflora* and *Themeda triandra* in a matrix of heath species on the longitudinal dune systems suggest that much of the north coastal plain would have been more grassy than heathy. Heath may have survived as a formation on poorly-drained ground, rocky outcrops, and higher rainfall areas in the southeast of the region. Many heath species may have survived as understorey plants in forest refugia. It is interesting to note that evidence of heath as a formation at Waterhouse Point, now the driest part of the Northeast, was coincident with the movement of the sea to present levels (Thomas 1991).

The Northeast has a distinctive biophysical environment. It is a region as much notable for its absences as its presences, and it is the part of mainland Tasmania with the greatest environmental affinities to the southeast Australian mainland. This does not mean that the region lacks conservation worth. There are many parts of it with outstanding conservation significance, including Waterhouse Point (e.g. Kirkpatrick & Tyler 1988, Kirkpatrick & Harris 1995), the Great Northern Plain (Kirkpatrick & Wells 1987), various populations of rare species (e.g. Coates 1991; Lynch 1993, 1994), Paradise and Mathinna Plains (Ellis 1985; Kirkpatrick, Gilfedder & Fensham 1988) and Blue Tier (Kirkpatrick, Gilfedder & Fensham 1988; Whinam et al. 1989; Kirkpatrick & Fowler 1996), among the areas without secure reservation alone. The secure reserves also have great conservation significance, especially Ben Lomond National Park (Davies & Davies 1989) and Mt Barrow State Reserve (Davies & Davies 1990) and Mt William National Park.

Unfortunately, the Northeast resembles southeast mainland Australia more than most of the rest of Tasmania in more than just its biophysical environment. It is further along the path of resource depletion, landscape deterioration and biodiversity loss than much of the rest of Tasmania. The natural landscapes that remain deserve protection from the clearing that has been so rife in the region over the last two or three decades (Kirkpatrick & Dickinson 1982, Kirkpatrick 1991).

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Aspects of Forest Conservation in Northeast Tasmania

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Abstract

A review of aspects of forest conservation in northeast Tasmania is presented in the context of State, national and international concerns about the conservation of biological diversity and against a background of the evolutionary changes in vegetation and the current range of different environments that occur there. Whilst there has been comparatively poor development of a distinctive regional flora or vegetation, beta diversity in the region is high because of the high turnover of environments in relatively short distances. There are some physical environments and forest vegetation types which are inadequately reserved and more effort is needed to ameliorate the possibly detrimental effects of fragmentation. There is a need also for informed off-reserve management as well as for management of the reserves which are already in place.

Introduction

The theme of this discussion is biological conservation in Tasmania's Northeast. Conservation evaluations are usually made at the local, regional, State, national and international levels. They consider biotic, geophysical, climatic, biogeographic, land-use and social aspects of the area being evaluated. They should also consider temporal variation. For example, are the alpine or rainforest communities important relicts of a past more widespread vegetation? Is today's mature forest a successional stage on the way to a pioneer community and vice versa? Are there indications of refugia which may be important for conservation in the event of human-induced climate change? What are the prospects for management of reserves by benign neglect? Do agricultural clearing, recreational use, forestry and mining activity have long-term adverse effects through fragmentation of habitats?

This presentation offers a brief review of the current state of conservation (in the sense of formal and proposed reserves and land use) in the context of the above topics for Tasmania's Northeast.

The United Nations Convention on biological diversity and the roles of Australia and Tasmania

There is a very real sense in which the global position of northeast Tasmania is important for nature conservation evaluation. Australia is signatory to the United Nations Convention on the Conservation of Biological Diversity (the UNCED Convention). Thus there is at the minimum a political need to undertake analyses of what this means for Tasmania (and its component parts) to decide what is relevant or important for the conservation of biological diversity.

The signing, ratification and adoption of the UNCED Convention had a profound effect on the preparation of plans and National Strategies, and on the evaluation of conservation measures worldwide, but whether it has actually led to any increase in on-the-ground measures to conserve biological diversity is another matter. Many countries are preparing or have prepared Action Plans, including Australia, which has produced a draft strategy now awaiting national acceptance. One of the items needed to implement this strategy and other documents such as the National Forest Policy Statement is to ensure that there are comprehensive, adequate and representative samples of the elements of biodiversity in reserves. This proposal should be examined at the regional, State and national levels.

In the Convention, biological diversity is defined as being made up of three components: the richness of species that occur in a place, the diversity of their genetic systems, and the diversity of habitats in the landscape. What makes the Northeast special is perhaps not so much the first two as the third. The region has a relatively high turnover of climatic and physiographic environments over very short distances, even in comparison with the relatively high density of habitats per unit area in Tasmania generally, let alone compared with elsewhere in Australia. This diversity has given rise to the sorting and definition of a relatively high diversity of communities in the landscape and this has been achieved with a relative paucity of local endemic species to effect the observed changes in vegetation. The levels of diversity have been achieved with relatively little evidence, in the higher plants at least, of micro-evolution leading to speciation and adaptive radiation as appears to have happened on the Central Plateau and in west Tasmania. In fact the evidence suggests the opposite, that there has been a reduction in species diversity through the Tertiary (Macphail & Hill 1983).

What are the values of northeast Tasmania in the world context for biodiversity conservation? There are fossil sites there which are of some significance and which inform us about the past evolution of vegetation. The early sites in the Northeast (Macphail & Hill 1983, Hill 1990, Carpenter et al. 1994) were rich in species from tropical and temperate areas, and by the Oligocene, sites

Fig. 1. Nature Conservation Regions of Tasmania.

Vegetation. The region contains a diverse array of vegetation types thanks largely to the rich diversity of physical environments that are found here. Ian Thomas and Bob Ellis (see papers, this volume) have highlighted the importance that Aboriginal and European fires have had on the structure and character of the vegetation within this landscape.

Fauna. The vertebrate and invertebrate components of the fauna in the region are examined in other papers from this symposium.

Is northeast Tasmania a region for the purposes of conservation evaluation?

State Government agencies have divided the State into Nature Conservation Regions (NCRs; fig. 1) for the purposes of conservation evaluation. These NCRs are based on the floristic zones of Specht et al. (1974) and Orchard (1988). Table 1 gives some figures on the occurrence of some conservation values in the Northeast as defined by NCRs 5 and 6. Comparatively few of these values are confined to the Northeast, although some have most of their occurrence there.

were rich in high-latitude, high-altitude species and attained much higher diversities, at least in rainforest vascular plants, compared with the rainforests in the area today.

At the local scale, some of the values offered by the Northeast are as follows:

Social. The area supports a society based on farming, mining, forestry, recreation and tourism and is set in a mixed cultural and natural landscape which is imbued with a strong sense of its Aboriginal and European heritage. The natural values are a primary facet of this array. Much of the fertile part of the Northeast is laid out in a landscape that would have satisfied the aesthetic sense of Capability Brown, and which still has obvious appeal, as do the spectacular beaches, granite coastlines and rugged dolerite-capped mountains.

Physical. There is a diversity of physical environments because of the variability in geology, geomorphology and soils as well as climate. The integration of these facets brings the identity of the Northeast into sharp relief in Tasmania.

It is apparent from the distribution map that the number of endemic vascular plant species in northeast Tasmania is relatively low (fig. 2), and no regional centres of endemism are present (fig. 3). Why? One major reason is that fragmentation and isolation from the rest of Tasmania (but not always from the Australian mainland) has been going on for a very long time. The start of the break-up of Gondwana occurred about 120 million years ago and there has been the subsequent (or consequent) formation of the Midlands Graben, further isolation by the South Esk and Break O'Day River valleys, and then periodic unification with and separation from the Australian mainland during the wave of glacials and interglacials. Thus there has been ample opportunity for reinvasion of the region by plants from the north, but little opportunity for reinvasion from the west and south. The above-mentioned work by Bob Hill and his colleagues has shown that the late Oligocene - early Miocene rainforest floras of northeast Tasmania were similar in species richness and content to those in the west. It appears that isolation from the rest of Tasmania and periodic contact with the Australian mainland, together with subsequent environmental fluctuations, have not been conducive to the development of a pronounced regional flora, and that the subsequent environments (perhaps also with the

Table 1. Occurrence of some conservation values in northeast Tasmania. Sources: (1) Flora Advisory Committee 1994; (2) Brown et al. 1983; (3) Jarman et al. 1984, 1991, 1994; (4) Kirkpatrick et al. 1988; (5) Duncan & Brown 1984; (6) Kirkpatrick & Brown 1991; (7) Lewis et al. 1991.

Conservation value	No. of units in Tasmania	No. in Northeast	No. (largely) confined to Northeast
Species:			
Plants at risk (1)	620	c. 130	c. 20
Endemic plants (2)	320	97	4
Communities:			
Rainforests (3)	40	3	0
Wet eucalypt forest (4)	67	27	(1)
Dry sclerophyll (5)	37	19	(1)
Environmental domains A (6)	8	4	0
Environmental domains B (6)	68	19	6
Environmental domains C (7)	30	11	0

influence of humans through fire) have eliminated much of the distinctively Tasmanian element. Perhaps more concrete evidence of speciation is to be found in other groups. If so then one probably should target very old groups in the lower plants and invertebrates, but only those elements within those phylogenetic groups which have poor dispersal abilities, e.g. velvet worms and snails rather than tree ferns. Of course it may well be that there is and has been active evolution occurring at the genetic level that is not apparent yet at the species level. Thus it would be surprising if there were not ecotypic and ecoclinal variation within species either locally in the Northeast or across regions. Cases of such genetic variation have been documented by Menadue and Crowden (1983) for *Richea scoparia* and by Brown (1981) for the *Plantago tasmanica* complex, and both taxonomic groups are found in the Northeast.

Ecosystems and environmental domains

An environmental domain is simply a set of areas which are similar in their climate, geology, soils and physiography. With the advent of geographic information systems it is relatively simple to use characteristics such as geology, altitude, radiation, rainfall and temperature to produce a coherent picture of similar regional environments. As well as the formal land systems approach adopted by the Tasmanian Department of Primary Industry (e.g. Pinkard (1980) for northeast Tasmania), at least two such environmental domain analyses of Tasmania have been undertaken, one by Lewis et al. (1991) and one by Kirkpatrick and Brown (1991), both at the behest of the Resource Assessment Commission Forest and Timber Inquiry. At the eight-group level, none of the domains defined by Kirkpatrick and Brown (1991) is unique or confined to northeast Tasmania. At the 68-group

Fig. 2. Numbers of endemic vascular plant species per 10 x 10 km grid square in Tasmania (after Kirkpatrick & Brown 1984a).

Fig. 3. Zones of regional endemism in Tasmania (after Kirkpatrick & Brown 1984b).

1989) indicates that arboreal fauna are most abundant in sites of high nutrient availability. In northeast Tasmania, as elsewhere in the world, these sites are now fragmented in the landscape so that only relatively small populations are left. Do they remain viable?

Forest reservation in northeast Tasmania

In their strategy for world conservation entitled *Caring for the Earth* (International Union for the Conservation of Nature 1991), the International Union for the Conservation of Nature, together with the United Nations Environment Program and the World Wide Fund for Nature, have suggested a base-level reservation target nationally of 10% of each biome (the largest classificatory unit recognised by ecologists). This target is met in northeast Tasmania for rainforest (33% reserved) and for dry sclerophyll forest (10% reserved) but not for wet eucalypt forests (6% reserved). The categorisation of reserves is currently being examined by the Tasmanian Public Land Use Commission, but for the present

level, six are found only in the Northeast. Five of these relate to uplands on dolerite and Mathinna Beds bedrocks, where there is relatively high June or December radiation and relatively high mean temperatures in the warmest quarter of the year. The other domain is at low elevations on marine sediments, with a relatively high range in temperature. This latter domain corresponds closely with the distribution of the remaining patches of *E. pauciflora* woodlands in the far Northeast, which are presumed relicts from a more extensive population which may have occurred across the Bassian Plain during the glacial period.

Importantly, at the 68-group level, there are 19 different domains found in northeast Tasmania, 11 of which are either very poorly reserved or unreserved on a statewide basis. They all occupy areas of high agricultural potential or are coastal. Similarly, if the 30-domain resolution level of Lewis et al. is considered, 11 domains are found in northeast Tasmania, and those most in need of further reservation are those which elsewhere have been cleared for agriculture or for plantations. If we accept that these domains are representative of particular environments which are our most productive for plant growth for human use, it follows that they must also constitute a considerable resource for native biota. The work by Wayne Braithwaite and his colleagues (Braithwaite et al.

purposes I have included here State Reserves, other reserves and Recommended Areas for Protection (RAPs; see Brown & Hickey 1990, Working Group for Forest Conservation 1990). At the next level of classification, Kirkpatrick and Brown (1991) have mapped 39 forest community types at 1:500 000 scale. Some of these communities are well reserved, others are inadequately reserved, but by and large the productive forest types are well catered for by reserves (table 2). If a similar analysis is done for the 30 environmental domains of Lewis et al. (1991), there are several key domains not represented or poorly represented in reserves (table 3). These domains include some of the coastal types but are mostly those that are of interest to the farming community. There is no direct evidence to suggest that any particular community or species is disadvantaged by lack of reservation of a particular domain. The absence of such particular sets of environments from the reserve system should act as a warning that there may well be unsurveyed elements of the biota for which conservation and reservation planning are required.

The simple act of reservation in itself is insufficient to ensure the continuing conservation of the biota currently in the reserves. It is important to establish how these reserves are arrayed in the landscape, and how the patterns of land use impinge on the conservation of species. In the case of the Northeast, the pattern of land use is summarised effectively by the land tenure map

Table 2. Percentages of forest communities by land tenure/land use in northeast Tasmania. Allo vert lf = *Allocasuarina verticillata* low forest; E. amy = *Eucalyptus amygdalina*; E. del = *E. delegatensis*; E. obl = *E. obliqua*; E. pau = *E. pauciflora*; E. reg = *E. regnans*; E. sie = *E. sieberi*; E. vim = *E. viminalis*; St Helens comp = St Helens complex.

Community	Reserved	Deferred	Wood Production	Private	Other
Allo vert lf	43	-	-	57	-
E. amy gravel	5	33	37	22	3
E. amy inland	-	-	-	100	-
E. amy coastal	15	26	22	33	4
E. amy doler	7	6	10	74	3
E. amy/E. obl	7	17	54	16	6
E. del forest	18	7	42	23	10
E. del tall for	5	9	61	12	13
E. obl forest	5	5	54	27	9
E. obl tall for	4	3	65	17	11
E. pau forest	-	25	51	17	7
E. reg forest	20	1	57	9	13
E. sie forest	6	10	61	11	12
E. vim wood	1	1	1	97	-
rainforest	47	6	37	2	8
St Helens comp	8	15	50	15	12

Table 3. Percentages of environmental domains (Lewis et al. 1991) by land tenure/land use in northeast Tasmania.

Domain No.	Reserved	Deferred	Wood Production	Private	Other
3	1	11	50	12	26
4	43	6	6	31	14
5	17	10	1	10	62
13	40	2	20	28	10
14	12	3	8	57	20
20	5	46	1	1	47
21	1	1	1	57	42
25	58	26	1	13	2
26	3	1	-	51	45
27	9	73	15	1'	2
28	2	1	4	-	93

(fig. 4) and this can be compared with the extent of forests (fig. 5). It can be seen from this map that there is considerable fragmentation of the forests both naturally through the intercession of mountain ranges and treeless, poorly drained areas, but also through the clearing of land for agricultural purposes and for the establishment of softwood, and more recently hardwood, plantations. The effect of this fragmentation on the viability of reserves and connecting corridors of native vegetation remains to be determined.

Another major consideration for conservation is the effective management of the forests which are reserved, especially for fire and for disease. There are a number of forest diebacks which are prevalent in particular situations in the Northeast, and these are as much problems within reserves as outside. Examples include regrowth and gully dieback in Lower Marsh Creek Forest Reserve and Tombstone Creek Forest Reserve and elsewhere (caused by drought and *Armillaria*, see Wardlaw 1990). There are also high-altitude diebacks which are thought to be caused by soil microbes. The microbial activity in turn is associated with successional changes after fire in the understorey of wet eucalypt forests (Ellis 1985). Other examples include myrtle wilt (Packham 1991) at Mt Maurice and Blue Tier, and *Phytophthora cinnamomi* infection (Wardlaw & Palzer 1988) in reserves such as Mt William National Park. The impacts of these latter diseases are likely to be exacerbated by the increasing pressure on reserves from recreationists and from ecotourism.

In conclusion, there are some general attributes of the forests and landscapes as well as of approaches to
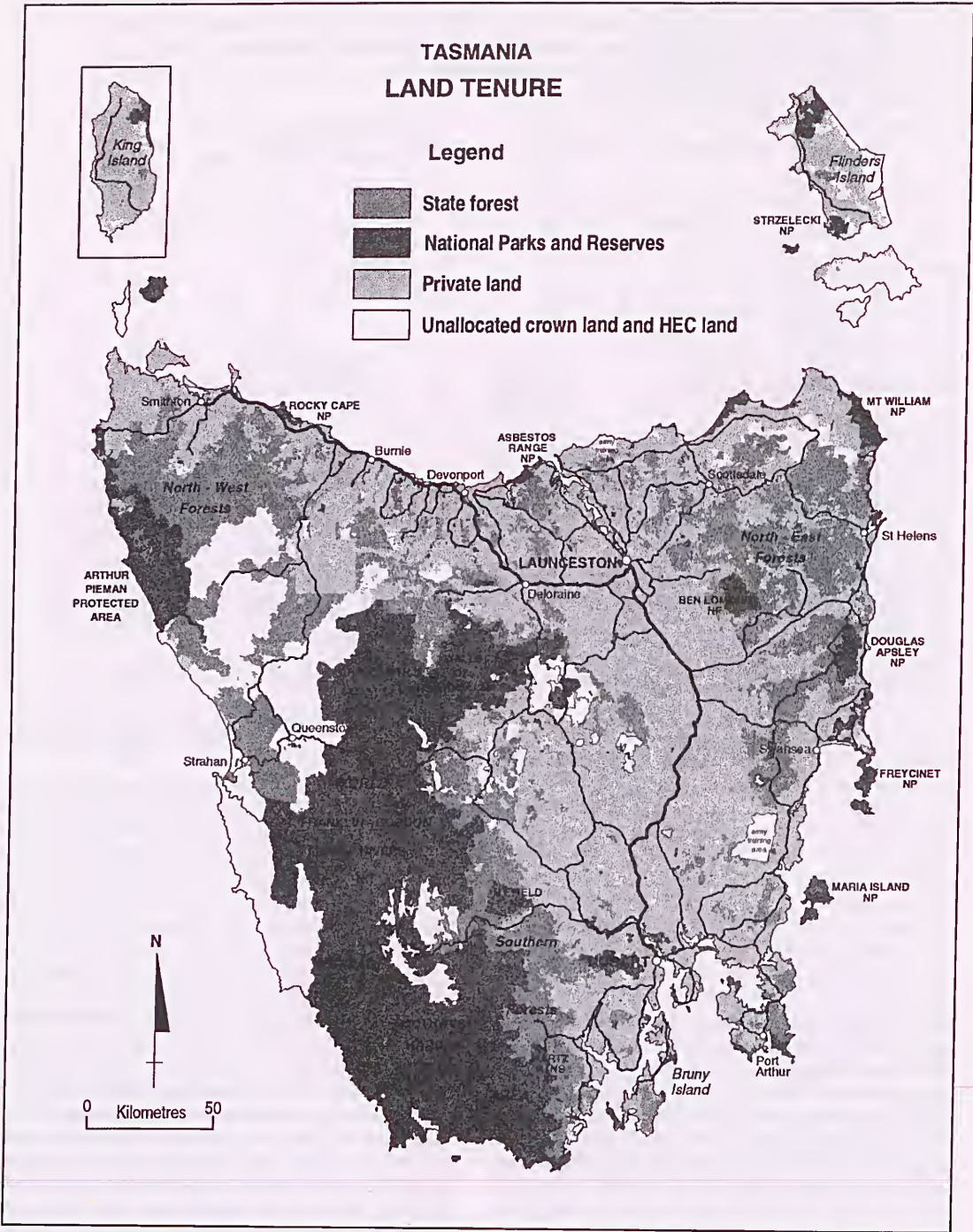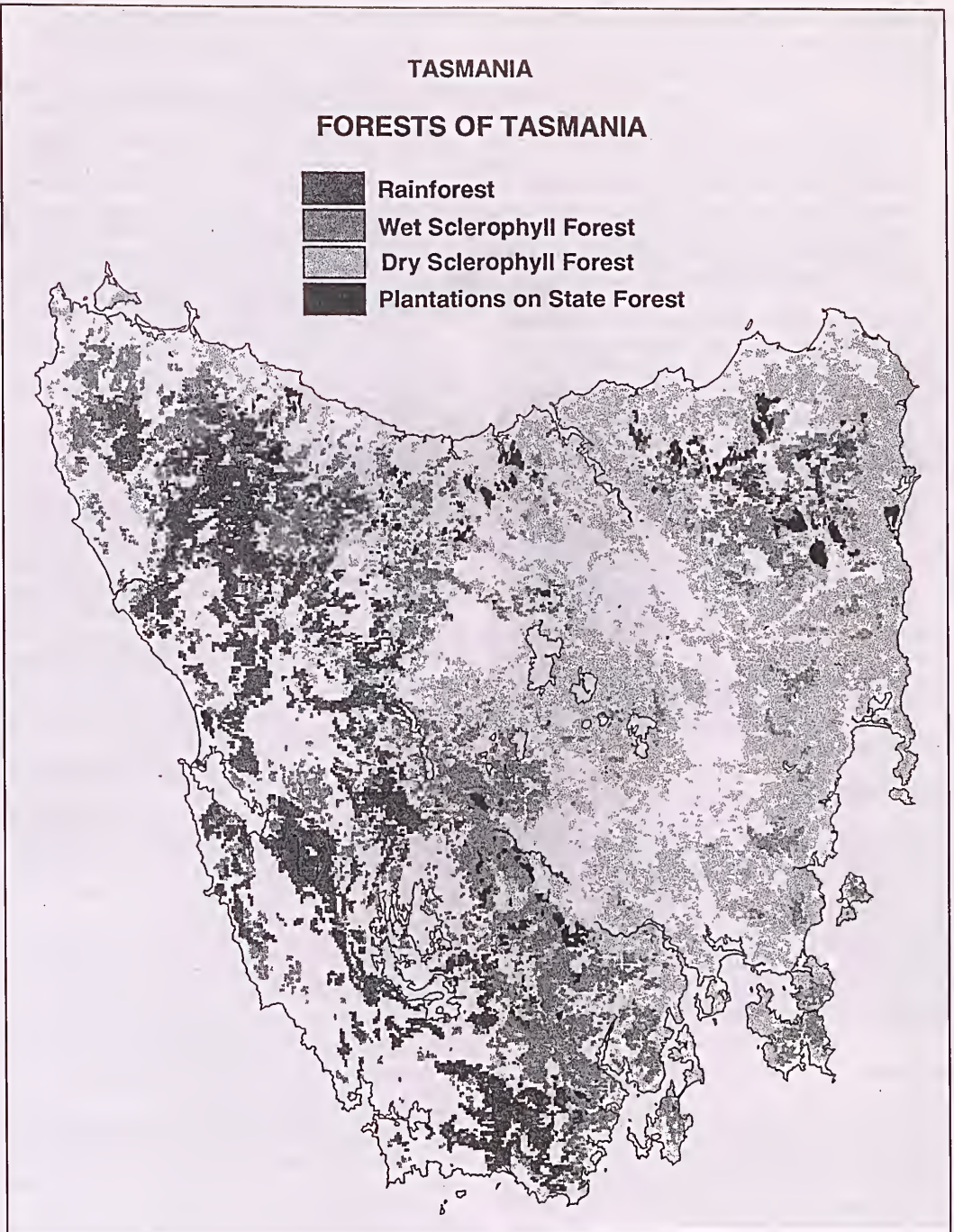
Fig. 4. Land tenure in Tasmania.

Fig. 5. Forest vegetation in Tasmania.

management which are needed to achieve forest conservation. These elements are shared by northeast Tasmania with the rest of Tasmania, the nation and the globe:

• It will not be possible with the current rates of land development and the pressures on the ecosystems to achieve conservation aims with a species-by-species approach.

• A core network of reserves is needed to provide the basis for conservation efforts.

• Landscape effects are some of the most important facets of conservation which remain to be addressed, particularly the effects of fragmentation and the utility of corridors. The impacts of plantations are such that it seems likely that an industry based on both plantations and native forest utilisation is a better option for conservation values in the longer term than strategies based solely on plantations.

• The corollary of such a mixed strategy is that there is a need for off-reserve management which is environmentally friendly, including benign silvicultural systems and systematic planning to ameliorate the impacts of invasive species.

• The management of lands both on and off reserves needs to recognise and build in the importance of the role of humans, fire and other disturbance mechanisms.

Acknowledgements

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Summing Up: Is Northeast Tasmania a Biogeographical Region?

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Abstract

Modern biology is based not on the classification of species, but on their systematisation, or arrangement in a system which reflects historical relationships. Looking at Tasmanian landscape units in an analogous manner, northeast Tasmania (as defined for this symposium) is historically composite and not a monophyletic region. It is suggested that landscape systematics could be advanced by making use of geomorphic entities as well as biological species in historical reconstructions.

Introduction

In this paper I argue the case for landscape systematics as a successor to landscape classification, and I suggest that from a systematic point of view the Northeast is an historically composite area. My answer to the title question, in other words, is no, but my reasoning may seem novel to some readers. I therefore devote the following short section to an overview of traditional approaches to landscape classification in Tasmania. The remainder of the article builds on these familiarities and promotes historical biogeography as a framework for understanding the contemporary Tasmanian landscape.

Landscape classification

Recent regionalisations of Tasmania have been devised as mosaics of biogeographic provinces (Neboiss 1977), land systems (e.g. Pinkard 1980 for northeast Tasmania), natural regions (Orchard 1988), Nature Conservation Regions (Orchard 1988) and environmental domains (Kirkpatrick & Brown 1994). All these mosaics are classifications in the formal sense, i.e. sortings of landscape units according to measurable or perceived properties of those units. For example, the hierarchical classification procedure used by Pinkard (1980) begins with the recognition of 'land systems', which are landscape units with similar elevation, annual rainfall, parent geology and generalised landform. Land systems can be divided on minor differences into 'land components', or aggregated on similarity into 'land zones'.

Natural discontinuities in the landscape have also been recognised in the regionalisations noted above. All schemes, for instance, respect the Great Western Tiers as a regional boundary. It would be difficult to justify including the high country northeast of Great Lake (1 100+ m elevation) and the plains near Bracknell (200 m) in a single geographical category, although the two areas are less than 20 km apart.

Regardless of how the sorting is done, the result of a landscape classification is a mosaic of patches with some degree of within-patch homogeneity. From a biogeographical point of view the existing classifications are only tentative, since plant and animal distributions were either ignored as properties of Tasmanian landscape units or given light weightings. There were good reasons for this emphasis on non-biological features of the landscape. Only very recently have large, accurate data sets become available for examining the distributions of species and communities in Tasmania. More importantly, it is an ecological truism that plants and animals distribute themselves along environmental gradients with fastidious attention to climate, soil nutrient levels, etc. Non-biological landscape properties have therefore been trusted as surrogates for species distributions. Few would doubt that a field survey of a wide range of plant and animal genera would show the Great Western Tiers to be an important biotic boundary, as well as an abiotic one. I am not aware, however, that any of the recent regionalisations have been broadly tested by field surveys, or that regional boundaries have been adjusted to make them more biogeographical. A landscape classification of Tasmania based entirely on plant and animal distributions has apparently never been attempted.

Beyond classification

Classification of objects in the natural world was in vogue in the 18th and 19th centuries, and hierarchical classification is still celebrated in textbooks as the basis of modern biology. Nevertheless, for more than 100 years the intellectual underpinning of the life sciences has been systematisation, not classification (O'Hara 1993). In the mid-19th century Charles Darwin and others realised that animals and plants could not only be sorted according to their properties, but also arranged according to their relationships with one another. In Darwin's view, the key relationship was an historical one, namely proximity of descent. An arrangement, or system, 'must be strictly genealogical to be natural' (Darwin 1859, cited in O'Hara 1993). In hindsight, we can see the assignment of several

species to the same genus by Linnaeus as implicit recognition of the relatedness of those species. The Darwinians made that relatedness explicit, and went on to claim that all extant and fossil species are historically related to one another.

Classification and systematisation are sometimes confused, even by biologists. A simple remedy for confusion is to imagine a large family reunion, and to think of various ways to group the people attending: by sex, by hair colour, by age, etc. It would be easy to devise a hierarchical classification in which every individual was uniquely assigned a place according to his or her physical characteristics. It would likewise be easy to draw up a family tree showing how each individual was related to every other individual. The family tree would be a system rather than a classification, and it can be constructed without reference to any characteristic other than sex.

Another way to understand the difference between classification and systematisation is to consider the two kinds of identification keys. Natural keys separate taxa according to the presumed sorting of characters in the evolutionary history of those taxa. Artificial keys separate taxa using whatever characters are convenient for doing so. At some stage in the keying process, an artificial dichotomy may create composite taxa containing morphologically convergent but only distantly related species. At another stage, an aberrant species may be separated 'too early' from a mixture of its own and unrelated lineages. These should not be seen as faults of the artificial key, which is only designed to be useful, not systematic.

The difference between classification and systematisation can also be seen very clearly in the elegant phytosociological studies of Dr Jamie Kirkpatrick and his associates. The vegetation of Tasmania has been sorted into a large number of plant communities according to the floristic and structural properties of the vegetation alone. The resulting classification has no geographical or historical content whatsoever. Spatial information has to be appended to community descriptions because geographical location is not one of the properties used to define communities. If we want to know additional localities for community X, we have to go into the field to look for them. Temporal relationships, likewise, have no place in phytosociological sorting. Community Y may indeed be a sere in a succession leading to community Z, but this hypothesis is not implicit in the community classification.

I do not mean to suggest that there is anything defective in the phytosociological classification procedures of Kirkpatrick et al. I am only pointing out that the natural objects resulting from the their sorting, namely plant communities, have not been arranged into a system which specifies their geographical or historical relationships. Modern plant taxonomy, on the other hand, is firmly based on evolutionary hypotheses about the relatedness of

species and higher taxa, and botanists are at pains not to assign a new species to a taxon to which it doesn't belong in the accepted evolutionary scheme, i.e. to the wrong lineage.

Landscape systematics

We can, if we wish, progress from 'only useful' landscape classifications of Tasmania to landscape systems which encapsulate the shared histories of Tasmanian landscape units. The reader bewildered by the phrase 'shared histories' should consider the following trivial examples: (1) the Tamar Graben and the Mt Arthur/Mt Barrow/Ben Lomond block are historically related because both have their origin in a single faulting episode, and (2) the Ben Lomond Plateau and the adjoining scree slopes are historically related because both owe their current forms to the same glacial and periglacial events.

If the landscape units in our system are defined geomorphologically, then the history we reconstruct will be largely geomorphological. However, since every major event in landscape history has biological consequences, we can expect to see traces of such events in contemporary biotic patterns, and we can use those patterns to assist our reconstructions. Suitable methods have already been developed by cladistic biogeographers (for overviews, see Nelson & Platnick 1981, Humphries 1992 and Morrone 1994). We begin by searching for areas of endemism, i.e. landscape blocks defined by the more or less congruent ranges of a number of species. We next select groups of related taxa represented as local endemics in such areas, and for each group establish (or borrow from the literature) a likely phylogeny. We then replace the taxa at the tips of the evolutionary branching diagrams with the areas of endemism they inhabit, and using an appropriate algorithm, derive a generalised area cladogram which postulates an evolutionary history for the land areas under consideration.

Cladistic biogeography has had its greatest successes in cases where terrestrial areas of endemism are separated by ocean basins. Branching points in the resulting area cladograms can be interpreted as vicariance events which physically separated landscape blocks and their resident flora and fauna, with subsequent differentiation of the separated biotas. The separation events are apparent in the geological record as well, and can sometimes be dated by geologists with a precision of a few million years.

Within-continent analyses have also produced useful area cladograms, e.g. for Africa using montane spider faunas (Griswold 1991), for Australia using vertebrates (Cracraft 1991) and for east Australia using higher plants (Weston & Crisp 1994). In such cases the areas of endemism involved may have been separated in the past by dispersal barriers other than ocean basins. Such barriers may since have disappeared, allowing sister taxa to meet parapatrically or sympatrically, and confusing a once-simple pattern of distribution. Other sources of

biogeographical noise, such as extinction events and unusually widespread species, can also obscure an historical signal in a within-landmass reconstruction. Smaller land areas, furthermore, have smaller numbers of species available for analysis, making it easier to devise a generalised area cladogram but harder to believe in its generality.

There are, nevertheless, what appear to be disjunct areas of endemism within Tasmania. Among them are southwest Tasmania west of Tyler's Line (Tyler 1992, Mesibov 1994), the Central Plateau, Plomley's Island (Mesibov 1994) and the southeast Tasmanian block of high *Eucalyptus* endemicity (Davies 1974, Potts & Reid 1985). As cladograms become available for species represented in these areas as local endemics, it should become possible to use cladistic biogeography to clarify the historical relationships of these landscape units.

Systematics of the northeast Tasmanian landscape

Even before we attempt a broadscale historical reconstruction for Tasmania, we can see that northeast Tasmania, as defined for this symposium, is a composite area. Several speakers have reported that the far Northeast is home to 'toehold' species most closely related to (or identical to) mainland taxa (see articles in this volume by Cameron; Harris & Kirkpatrick; Horwitz; and Tyler). This suggests that 'toeholding' is the result of invasion of northeast Tasmania during dry periods in the Quaternary. The biogeographical history of the coastal plain is thus part of the history of southeast Victoria and the Furneaux Group, and the toeholds represent an overlap of histories as well as biotas. We have also been told that endemic species restricted to north or east Tasmania extend into the Northeast, suggesting that portions of northeast Tasmania are historically tied to adjoining landscape blocks.

More to the point, the species endemic to northeast Tasmania are in fact endemic to smaller areas within the Northeast, such as Plomley's Island (Mesibov 1994; Smith, this volume) and the north coastal plain (Cameron, this volume; Harris & Kirkpatrick, this volume) and no species yet mapped has a range neatly bounded by the Tamar and the Fingal Valley limits for northeast Tasmania recognized for this symposium. An analogy can be drawn between biogeographical units such as Plomley's Island and southern South America. The latter is characterised by plants and animals more closely related to taxa in Australia and New Zealand than to taxa found elsewhere in South America. 'South America' as a landscape unit might be regarded as a biogeographical realm in a non-historical classification, but historical biogeographers see it as a composite area. Northeast Tasmania is composite for precisely the same reason. In historical terms, it is clearly not a monophyletic assemblage of landscape units.

Beyond biogeography

The known and suspected areas of endemism within Tasmania are well-defined but not contiguous; the map of Tasmania consists of biogeographically fascinating hot spots of endemicity and a cool background of landscape units whose biota seems to tell us little about Tasmanian landscape history. Nevertheless, that cool background is historically related to the hot spots. How can we include all parts of the map in a Tasmanian landscape system?

I suggest that geomorphological information can fill in many of the gaps, both in space and time. Biologists are used to thinking of landforms as more or less stable over the periods during which plants and animals differentiate, disperse and become extinct in response to climate changes. Geomorphologists know that landforms are sensitive to precisely the same climate changes, and that major climate shifts can be detected, and often dated, in the weathering and deposition records. We already know how to classify landscape units according to their combined geological/geomorphological and faunistic/floristic properties. Perhaps it is time to begin to systematise those units, i.e. to reconstruct the concordant evolution of landform species and biological species.

We have seen during this conference that there are a substantial number of congruences in plant, animal and landform distributions in northeast Tasmania. There are also some obvious shared discontinuities, i.e. significant changes in flora, fauna and landform over short distances. When did these discontinuities originate? At any one discontinuity, can we determine which of the two landscape units is more 'derived' in the phylogenetic sense? Which events in the biotic history of the Northeast correspond to which landform changes? Is the early Tertiary downthrowing of the Tamar Graben reflected in plant and animal evolution at a higher level in the taxonomic hierarchy than the late Tertiary/Quaternary glaciations? Did 'toeholding' precede or follow the uplift of the coastal plain?

Such questions may become easier to answer as geomorphological investigations in Tasmania become more sophisticated, and tentative historical reconstructions may be more in evidence at a future symposium on Tasmania's Northeast.

Acknowledgements

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Recommendations

Professor J.B. Kirkpatrick led an open discussion of management and research topics at the end of the last session of the symposium, on 6 February 1995. The following recommendations arose from that discussion:

Land management

- The security of tenure of existing reserves should be increased, especially in the cases of Waterhouse Point, St Helens Point, Mt Pearson, the lower Forester River flats, Recommended Areas for Protection (RAPs) and Deferred Forests.
- Further land clearance, habitat fragmentation and artificial drainage should be restricted, and efforts should be made to restore degraded land and rivers.
- Streams, soaks and springs and their associated vegetation should be better protected.
- More thorough surveys should be carried out, including invertebrate surveys, before major disturbances to forest are permitted.
- Dunes should be stabilised where sand movement is threatening biological diversity.
- Access to beaches through dunes should be limited.
- Extension work and education in the conservation of biological diversity should be increased.
- Efforts should be increased to control feral animals and plants, e.g. deer, trout and *Euphorbia*.
- Future assessments of land capability for agriculture should include biological resource inventories.

Research

- Further investigations should be conducted into the nature of Plomley's Island, the East Tamar faunal break and the 'Fingal Gap' in plant and animal distributions.
- More detailed taxonomic and other studies of northeast Tasmanian invertebrates should be carried out.
- Greater community involvement in Government, museum and university research projects should be encouraged.
- More thorough botanical surveys should be carried out in the Waterhouse Point area.
- The marine and freshwater biota of northeast Tasmania should be studied in more detail.
- Studies should be initiated which monitor long-term changes in habitats and biological communities.
- So-called 'toehold' species (Victorian or Bass Strait species restricted, on the Tasmanian mainland, to the far Northeast) should be targeted in conservation studies.

Other

- A levy on exploitative enterprise should be introduced to help fund research into aspects of biological conservation. Alternatively, a fixed proportion of rates, land taxes or National Park entrance fees could be allocated to such research.

Earth science and land use

Forestry in Northeast Tasmania

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Abstract

State Forests in Bass District (northeast Tasmania) are managed in accordance with a range of Government legislation (Forestry Act and Forest Practices Act) and organisation policy and inter-agency agreements. Such management requirements are fully set out in the draft Bass Forest District Forest Management Plan. Management issues in the District include:

• increasing the area under plantation to increase the annual supply of plantation-grown wood products,

• satisfying the demands for biodiversity management and adequate protection of representative biotypes,

• protecting special values in off-reserve management zones including those for eagles' nests, archaeological sites and streamside habitats, and

• providing an economic return from wood production activity as well as benefits to the public and the State from non-wood values.

At times, the objectives of management can be in conflict, in which case management prescriptions that will achieve an overall best result are applied. This is exemplified by the need to undertake landscape management planning on the mountains around Scottsdale to minimise the visual impact of timber harvesting. Such landscape planning will highlight the areas that are not visible and indicate the areas where harvesting prescriptions will be constrained or where harvesting will not be considered. Management can only take place, however, within the framework of current knowledge. Recently completed research of importance for management includes studies on geomorphology and archaeological research on mining in the Lisle and Denison goldfields and on sawmilling in the Sideling and Mt Horror forests. A botany manual is in preparation and *Phytophthora* risk areas have been identified. Management practices are also constantly under review.

Farming in the Northeast Environment

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Abstract

Environmental aspects of farming in northeast Tasmania are examined from the perspective of a family with more than 100 years of experience in the region. Farming and mining have been integral in the European impact on northeast Tasmania. Mining was a pioneer industry bringing population and communications, but it was careless of the land; examples of negative impact are given. Modern farmers, however, continue to benefit from aspects of the mining heritage: the Winnaleah Irrigation Scheme and the Mt Cameron water race, both originally constructed to supply water for mining; the burning of rainforest by miners on Blue Tier and Star of Peace, which created excellent grazing land; and on a smaller scale the Boobyalla Mine tailings, used with cement to make all-weather stockyard floors. On basalt soils, massive and diverse forests were completely cleared to make way for extremely productive dairy, cropping and beef farms, but such land makes up less than 5% of the region. Today's farmers need to make productive and prudent use of lower-quality land. An example is the north coastal plain, which was managed for grazing by Aborigines before being settled by wool-growers. Dairying and cropping on the plain have recently begun. Tree plantings are needed on the plain for shelter, and adaptive water storage and drainage systems are required to allow steady production in an 'cither too wet or too dry' environment. The coastal plain is also very rich in wildlife, and while native birds and mammals compete with stock for grazing and can destroy crops, water birds are effective in controlling stock parasites. Farming in the Northeast competes for land with forestry and reserve-style conservation, and there is a need to guard against focussing on land classification and to think instead of integrated land use. Local farmers are deeply involved in both forestry and conservation; the speaker was partly responsible for the creation of Mt William National Park. In future, the diverse climate, topography and resource base of the Northeast will demand increasing diversity and flexibility in local farming enterprises. The challenge is to marry a culture of conservation with a culture of innovation in production and marketing.

Forest Soils of Northeast Tasmania: Distribution, Properties and Constraints for Plantation Forestry

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Abstract

Forest soils cover some two-thirds of northeast Tasmania. They are highly varied and reflect primarily the wide range of parent materials, climate and forest types occurring within the region. The soils are described in terms of 20 soil-physiographic units based on geology and native vegetation. Six major geological units are differentiated: 1) granite, 2) sandstone, 3) mudstone, 4) dolerite, 5) basalt and 6) Quaternary alluvium and aeolian sand. Native vegetation includes seven types: 1) low-altitude dry sclerophyll forest, 2) wet sclerophyll forest, 3) mixed forest and/or rainforest, 4) mid- to high-altitude dry sclerophyll forest, 5) alpine scrub and herbfield, 6) sedgeland-heath and wet scrub, and 7) coastal low woodland and scrub. The transition from dry sclerophyll forest to wet sclerophyll forest to mixed forest and rainforest reflects a significant increase in mean annual rainfall usually in association with increasing elevation. These trends are clearly shown in the soils by marked changes in morphological and chemical properties. For each soil-physiographic unit the dominant soils are described briefly in terms of environmental features, characteristic profile features and typical nutrient levels. The soils have been assessed and classified for constraints affecting plantation forestry. Soils with negligible or slight constraints for plantation growth (Productivity Class 1) include soils at lower altitudes under wet sclerophyll forest, mixed forest and/or rainforest. Exceptions are stony soils which invariably have severe constraints of restricted rooting conditions. At higher elevations soils under wet forest are very severely constrained by low temperatures. Soils under other types of native vegetation have severe or very severe constraints for plantation growth (Productivity Class 3 or 4). These include drainage impediments with high water tables under sedgeland-heath and wet scrub, low moisture and nutrient availability often with restricted rooting conditions under dry sclerophyll forest and coastal low woodland and scrub, and low temperatures under mid- and high-altitude dry sclerophyll forest and under alpine scrub and herbfield.

Introduction

Native forests cover 60% (517 600 ha) of northeast Tasmania on both private and public lands (largely State forests). They encompass a wide range of landforms, geology and climate which is reflected in the highly diverse pattern of soils. This paper summarises information acquired during recent soil mapping on the TASMAP 'Pipers' and 'Forester' 1:100 000 scale land tenure sheets. It also includes localised soil data collected elsewhere in the region during site inspections for plantation suitability. For earlier information on soils of the Northeast see Hubble (1946) and Pinkard (1980).

Environmental features

Soils are the product of their environment and they reflect the interaction of topography, climate and biologic factors (mainly vegetation but also including micro-organisms and larger fauna) acting upon parent materials through time.

Topography

Landform, slope angle, aspect and altitude all vary widely in the region, with relief generally increasing from the coast inland. Forested landforms are dominated by hills and mountains with only relatively minor areas of alluvial flats and coastal plains. Significant areas of hilly and mountainous land occur at elevations above 600 m. Slope angles vary widely but undulating (3-10%) and rolling (10-30%) slopes are generally associated with low hills, and steeper (>30%) slopes with dissected hill country and mountains.

Climate

The climate of northeast Tasmania varies from mild and subhumid (mean annual rainfall 600 mm) near the coast to cool and humid (mean annual rainfall >1 600 mm) in the mountainous highlands. Summers are generally dry, particularly in lowland areas nearer the coast which commonly experience pronounced soil moisture deficits. Summers are mild to warm and winters cool to cold with frequent frosts, particularly in inland localities and at higher elevations.

Vegetation

Forested land in the Northeast is dominated by native eucalypt and rainforests with a lesser plantation estate (30 000 ha) of hardwoods and softwoods. Where

accessible the native eucalypt forests have been logged either by clearfelling or by selective extraction. Of the total native forest area (517 600 ha) in northeast Tasmania, 364 200 ha (70%) is dry sclerophyll forest including coastal woodland and scrub, 101 900 ha (20%) is wet sclerophyll forest and 51 500 ha (10%) is mixed forest and rainforest.

The native forests show clear links with drainage, climate and geology. Rapidly draining coastal dune sands generally support heathy to scrubby communities often dominated by *Allocasuarina stricta* over *Banksia marginata* and *Monotoca elliptica*. In drainage lines and swamps the vegetation varies from sedgeland-heath and wet scrub-dominated communities to low open woodland or open forest often with *Eucalyptus ovata* and/or *E. amygdalina* over a sedgy or scrubby understorey. On better-drained sites where mean annual rainfall is below about 1 000 mm, lowland dry sclerophyll open forest predominates. The canopy is usually dominated by *Eucalyptus amygdalina* and/or *E. obliqua* with *E. viminalis* less prevalent. Along the east coast *E. sieberi* occurs widely. Very rocky sites on dolerite at elevations above about 600 m often support dry sclerophyll forests dominated by *E. delegatensis*.

Wet sclerophyll tall open forest predominates in areas where mean annual rainfall is between about 1 000 mm and 1 400 mm. It also often occurs on slopes with shady aspect in areas of lower mean rainfall. The major canopy species include *Eucalyptus obliqua*, *E. regnans* and/or *E. delegatensis* with *E. viminalis*, *E. dalrympleana* and/or *E. amygdalina* sometimes present. Shrubby, damp sclerophyll communities often occur, transitional to the dry and wet sclerophyll forests.

At altitudes above about 500 m or at lower levels where mean annual rainfall exceeds about 1 400 mm the vegetation is a mosaic of wet sclerophyll forest (often dominated by *E. delegatensis*), mixed forest and rainforest. The rainforest is usually callidendrous with *Nothofagus cunninghamii* and *Atherosperma moschatum* over a variety of ferns. The tree line occurs at an altitude of about 1 100 m where low forest grades into alpine scrub and herbfield. The vegetation here is dominated by species such as *Helichrysum backhousii*, *Richea scoparia*, *Orites acicularis*, *Epacris serpyllifolia* and *Baeckea gunniana* while species such as *Poa gunnii*, *Empodisma minus*, *Astelia alpina* and *Oreobolus distichus* become more prevalent in intermixed herbfield.

Parent Materials

Parent materials are highly varied and reflect geology, landforms and age. Age is reflected mainly in the degree of weathering, with older parent materials being more strongly weathered than younger materials. For example, road cuttings between Pipers River and Bridport show that undulating and rolling slopes are underlain by very strongly and deeply weathered Mathinna Bed

sedimentary rocks. Further south where relief is stronger and many slopes are steeper, the Mathinna Beds are much less weathered and often form outcrops of hard rock. Other rock types show similar patterns of weathering although dolerite often appears to be weakly weathered even in areas of relatively low relief.

Colluvial deposits (often shown as talus on Tasmanian geology maps) are prevalent on steep slopes in areas of higher relief, with particularly thick and extensive colluvium associated with dolerite. The colluvium was probably formed during widespread physical weathering, erosion and deposition during cold-climate episodes of the Late Pleistocene.

The geology of the region is dominated by Devonian granitic rocks, Silurian-Devonian sandstone, siltstone, mudstone (Mathinna Beds) and Jurassic dolerite. The granitic rocks include adamellite, granite and granodiorite. Other rock and sediment types include Triassic sandstone, Permian siltstone and sandstone, Tertiary basalt, Tertiary sediments and Quaternary sands, gravels and clays.

Regional soil pattern and properties

The soils of the Northeast have been separated initially according to six major soil-physiographic units based on geology:

1. Soils on granite;
2. Soils on sandstone;
3. Soils on mudstone;
4. Soils on dolerite;
5. Soils on basalt;
6. Soils on Quaternary alluvium and aeolian sands.

The granite subdivision has been extended to include Tertiary sediments derived mainly from granite. Sandstone and mudstone includes rocks of Silurian-Devonian, Triassic and Permian age. Mudstone also includes siltstone and slate.

The soil-physiographic units are then subdivided on the basis of native vegetation type. Seven major vegetation types corresponding to broad climate and drainage patterns are described:

1. Dry sclerophyll forest, including grassy open woodland;
2. Wet sclerophyll forest;
3. Mixed forest and/or rainforest;
4. Mid- to high-altitude dry sclerophyll forest;
5. Alpine scrub and herbfield;
6. Sedgeland-heath and wet scrub;
7. Coastal low woodland and scrub;

A listing of soil-physiographic units in relation to geology and native vegetation is given in table 1. These units also reflect distinct patterns and trends in soil-forming

processes resulting from marked differences in climate, topography and age. Figures 1 and 2 show the general relationship between mean annual rainfall, elevation, vegetation and profile features for soils on granite and dolerite.

Each soil-physiographic unit contains a variable number of discrete soil profile classes many of which have been defined, named and mapped for the Pipers and Forester sheets (Laffan et al., in press; Grant et al., in press). This paper summarises the major soil profile classes only within each soil-physiographic unit. They are described briefly in terms of environmental features, characteristic profile features and typical nutrient levels. Organic carbon (C) and total phosphorus (P) levels are used as broad indicators of soil nutrient status for forest growth. High levels of organic matter and total P are generally associated with a satisfactory supply of nutrients. However, exceptions may occur in very poorly drained organic soils. Low levels of organic C and total P usually indicate nutrient deficiencies.

Table 1. Soil-physiographic units in northeast Tasmania according to geology and native vegetation types.

Soils on granite
    under dry sclerophyll forest
    under wet sclerophyll forest
    under mixed forest or rainforest

Soils on sandstone
    under dry sclerophyll forest
    under wet sclerophyll forest
    under mixed forest or rainforest

Soils on mudstone
    under dry sclerophyll forest
    under wet sclerophyll forest
    under mixed forest or rainforest

Soils on dolerite
    under dry sclerophyll forest
    under wet sclerophyll forest
    under mixed forest or rainforest
    under mid- to high-altitude dry sclerophyll forest
    under alpine scrub and herbfield

Soils on basalt
    under dry sclerophyll forest
    under wet sclerophyll forest and mixed forest

Soils on Quaternary alluvium and aeolian sands
    under sedgeland-heath and wet scrub
    under dry sclerophyll forest
    under wet sclerophyll forest
    under coastal low woodland and scrub

Soils on granite

Under dry sclerophyll forest (135 300 ha, 26%)

The forest is heathy to shrubby dry sclerophyll forest dominated by *Encalpytus amygdalina* and *E. obliqua* over an understorey that often includes *Leptospermum scoparium*, *Epacris impressa*, *Pteridium esculentum*, *Acacia terminalis* and *Banksia marginata*. These soils occur on undulating (3-10%), rolling (10-30%) and steep (>30%) slopes of hills at elevations between about 50 and 300 m. They include moderately well-drained soils formed on strongly weathered granite bedrock together with imperfectly drained soils formed from Tertiary sedimentary deposits. Rapidly drained soils formed on relatively unconsolidated sandy and gravelly alluvial deposits derived from granite are described under soils on Quaternary alluvium and aeolian sands. On undulating and rolling slopes soil profiles are characterised by contrasting texture between upper and lower layers. Upper layers typically have very dark grey, coarse loamy sand surface horizons (A1) and bleached loose, coarse sand subsurface horizons (A2e) which overlie yellowish brown, very firm, sandy clay subsoils. Subsoils are coarsely structured with slow permeability and restricted root penetrability. On steep slopes soils tend to be stony and have gradational texture profiles with sandy loams overlying sandy clay loams. Soils formed from Tertiary sedimentary deposits usually have thicker (>70 cm) A2e horizons and hard, cemented humus and iron pans at the interface with clayey subsoils. Slightly more heathy forests develop on these soils with *Allocasuarina littoralis*, *Aotus ericoides*, *Baeckea ramosissima* and *Ricinocarpus pinifolius* commonly occurring in conjunction with the species found on the soils with shallower A2e horizons (above). Some soils formed on Tertiary sediments have texture-contrast profiles with shallow A2e horizons but the underlying clayey layers have more sand and gravel than related soils formed on granite bedrock. Chemical analysis shows that the soils have low nutrient status with very strongly acid pH, low levels of total 'P and medium levels of organic C in the surface horizons. Subsoils have strongly acid pH and low concentrations of both total P and organic C.

Under wet sclerophyll forest (49 000 ha, 9%)

The forest is usually dominated by *Eucalyptus regnans* and/or *E. obliqua* and occasionally *E. viminalis* with understoreys dominated by *Pomaderris apetala*, *Dicksonia antarctica*, *Coprosma quadrifida*, *Olearia lirata* and *Polystichum proliferum*. These soils occur mainly on rolling and steep hill and lower mountain slopes at elevations between 200 and 500 m. They are generally well drained with gradational texture profiles and moderate permeability. Soil profiles are characterised by very dark grey, coarse sandy loam or sandy clay loam surface layers overlying yellowish brown, coarse sandy clay loam or sandy light clay subsoils. Stoniness and soil depth are variable, but deep (>1 m) soils occur widely.

Shallower and stony soils are generally associated with rock outcrops. Chemical analysis shows that the soils are strongly acid, with high levels of both total P and organic C in surface layers. Subsoils are strongly acid with medium levels of total P and low levels of organic carbon.

Under mixed forest or rainforest (29 900 ha, 6%)

The vegetation is generally callidendrous rainforest or *Eucalyptus regnans*-dominated mixed forest. Common species include *Nothofagus cunninghamii, Atherosperma moschatum, Acacia dealbata* and, in the ferny understorey, *Dicksonia antarctica, Polystichum proliferum* and *Histiopteris incisa*. These soils occur preferentially on rolling and steep slopes at altitudes above about 400 m, or at lower elevations on slopes with shady aspect where mean annual rainfall exceeds 1 400 mm. They are generally well drained with gradational texture profiles and moderate permeability. Soil profiles are typified by thick (>20 cm) black, coarse sandy loam surface layers overlying brown, coarse sandy clay loam subsoils. A characteristic feature of the soils is weak or very weak moist strength in both surface and subsoil layers. Stoniness and soil depth are highly variable but deep (>1 m) soils occur widely. Shallow and stony soils usually occur in association with rock outcrops. Gravelly soils often with thin dark-coloured surface layers occur preferentially on slopes with northerly aspect where they generally support a more open eucalypt forest with a sparse shrubby understorey. At elevations above about 700 m some profiles have humus and iron pans in subsoils indicative of very strong leaching. Chemically the soils under mixed forest or rainforest are strongly acid and have high concentrations of both total P and organic C in surface layers. Subsoils have high levels of total P but low to medium levels of organic C. Soils under drier forest usually have lower levels of organic C in surface layers and subsoils.

Soils on sandstone

Under dry sclerophyll forest (87 300 ha, 17%)

Mainly shrubby dry sclerophyll forest dominated by *Eucalyptus obliqua* and *E. amygdalina* over an understorey that often includes *Lomatia tinctoria, Banksia marginata, Acacia terminalis, Lomandra longifolia, Pteridium esculentum* and *Leucopogon australis*. These soils occur on undulating, rolling and steep hill slopes at elevation between about 50 and 300 m. They include moderately well-drained and imperfectly drained soils with texture-contrast and gradational profiles respectively. They are all assessed as having slow permeability. Soils with texture-contrast profiles are characterised by dark-coloured sandy loam surface layers overlying bleached, structureless sands. Beneath occur poorly structured clayey subsoils often mottled grey. Humus-iron cemented pans usually occur in soils with thicker bleached sandy layers. Some profiles also have many or abundant quartz gravels in the surface and

subsurface layers. Soils with gradational texture profiles are characterised by dark-coloured sandy loam surface layers overlying yellowish-brown, sandy clay loam and sandy clay subsoils with grey mottles and dark-coloured earthworm burrows and casts. On steep slopes soils are typically stony with gradational texture profiles. Bleached layers are not as well developed as on easier slopes. Chemically, the soils have low nutrient status with very strongly acid pH, and low levels of both total P and organic C in surface layers. Subsoils are generally strongly acid with low levels of both total P and organic C.

Under wet sclerophyll forest (33 800 ha, 7%)

Mainly *Eucalyptus regnans* and/or *E. obliqua*-dominated wet sclerophyll forest, occasionally with *E. viminalis*. Understoreys are dominated by *Pomaderris apetala* and *Zieria arborescens* over *Coprosma quadrifida, Olearia argophylla, O. lirata* and *Pteridium esculentum*. These soils occur on undulating, rolling and steep hill slopes at elevations between about 100 and 500 m. They include moderately well-drained and well-drained soils with gradational texture profiles and moderate permeability. Profiles are characterised by dark-coloured sandy loam or clay loam surface layers overlying yellowish-brown or yellowish-red clayey subsoils. On steep slopes profiles are invariably stony and often shallow. Rock outcrops usually occur on very steep slopes. Chemically the soils have strongly or very strongly acid surface layers with high levels of organic C and medium or high total P. Subsoils are strongly acid with low organic C and medium total P.

Under mixed forest or rainforest (14 000 ha, 3%)

The vegetation is mainly callidendrous rainforest or *Eucalyptus delegatensis*-dominated mixed forest. The understoreys are often open with numerous ferns such as *Dicksonia antarctica, Polystichum proliferum* and *Rumohra adiantiformis*. These soils occur on rolling and steep mountain slopes at elevations between about 500 and 850 m. They are generally well drained with gradational texture profiles and moderate permeability. Profiles are characterised by dark-coloured clay loam surface layers overlying brown clayey subsoils usually with weak strength. Organic litter layers often occur on the soil surface. Stone content is highly variable but many to abundant stones typically occur in soils on steep slopes. At elevations above about 700 m profiles often have thin, hard iron pans in subsoils indicative of very strong leaching. Chemically the soils have very strongly to extremely acid surface layers with high levels of organic C and total P. Subsoils are very strongly acid with moderate to low organic C and high total P. At higher elevations levels of organic C and total P are usually lower in both surface layers and subsoils.

Fig. 1 Representative sequence of forest soils on undulating and rolling granite in north-east Tasmania showing soil features in relation to vegetation, mean annual rainfall and altitude.

VEGETATION

Heathy dry sclerophyll forest

Shrubby dry sclerophyll forest

Wet sclerophyll forest

Mixed forest

RAINFALL AND ALTITUDE

Mean annual rainfall (mm/yr)	800-1000	800-1000	1000-1400	1400-1800
Altitude (m)	50-300	50-300	200-500	400-800

SOIL TEXTURE

Texture in soil profile	Texture contrast profile: Deep sand over clay with humus and iron pans	Texture contrast profile: Sand over clay	Gradational texture profile: Sandy clay loam over sandy clay	Gradational texture profile Sandy loam over sandy clay loam

ORGANIC CARBON AND TOTAL PHOSPHORUS IN 0-10 cm

Organic carbon %	Medium (2-5)	Medium (2-5)	High (>5)	High (>5)
Total Phosphorus (ppm)	Low (<100)	Low (<100)	High (>250)	High (>250)

Soils on mudstone

Under dry sclerophyll forest (13 000 ha, 3%)

The vegetation is mainly shrubby dry sclerophyll forest dominated by *Eucalyptus amygdalina* and *E. obliqua*. These soils occur on undulating, rolling and steep hill slopes at elevations between about 60 and 200 m. They are generally moderately well drained with gradational texture profiles and moderate to slow permeability. Profiles are characterised by dark-coloured silty clay loam surface layers overlying pale-coloured or bleached silty clay loam or light clay subsurface layers. Beneath occur brown, silty medium clay subsoils usually with reddish mottles. Stone content is variable but profiles on steep slopes are generally stony. Chemically the soils have very strongly acid surface layers with low levels of organic C and moderate total P. Subsoils are strongly acid

with low organic C and total P.

Under wet sclerophyll forest (3 800 ha, 1%)

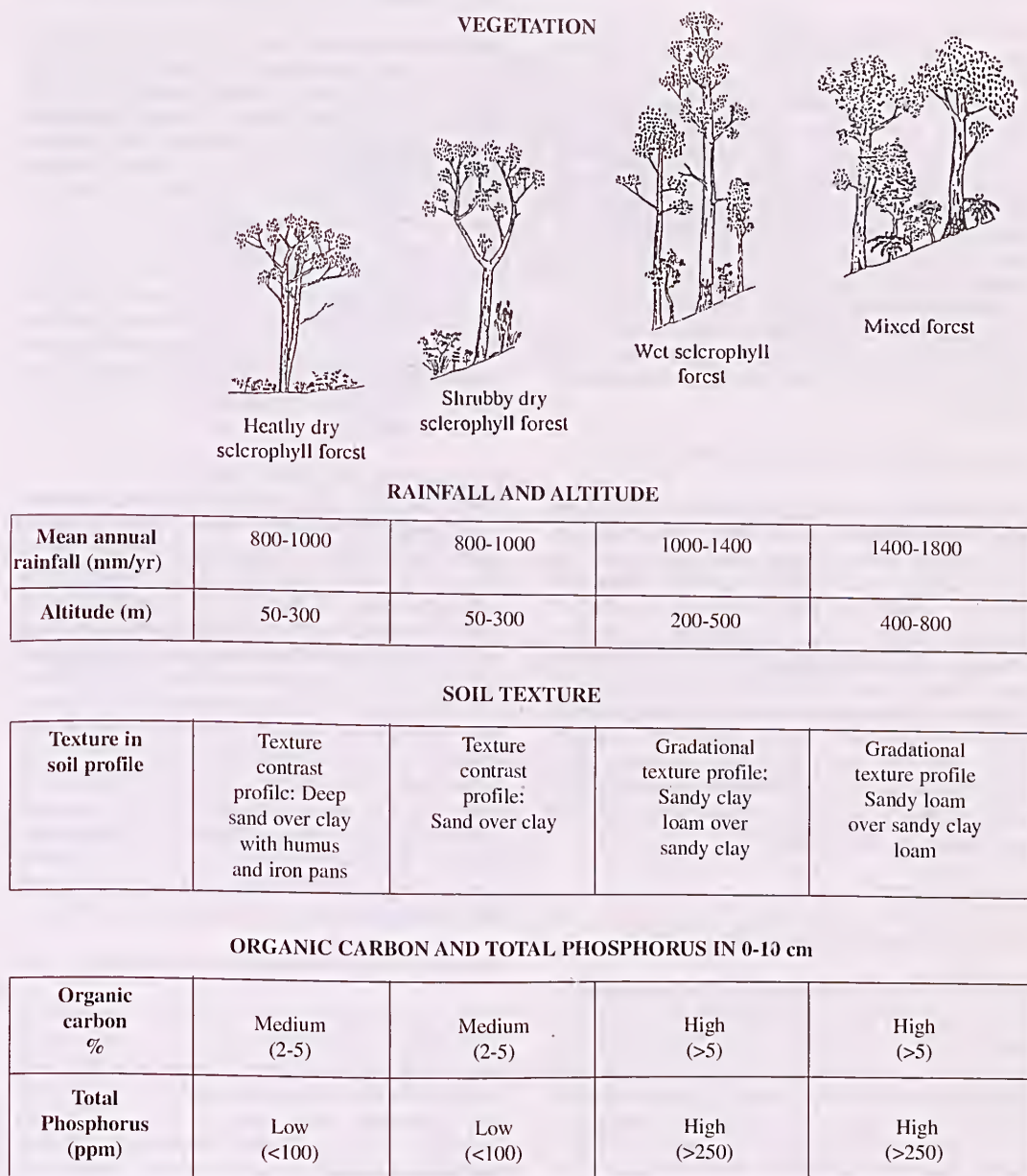Mainly *Eucalyptus regnans* and/or *E. obliqua*-dominated wet sclerophyll forest with an understorey dominated by *Acacia dealbata*, *Pomaderris apetala* and *Olearia argophylla* over *Coprosma quadrifida*, *Dicksonia antarctica* and *Polystichum proliferum*. These soils occur on rolling and steep hill slopes at elevations between about 100 and 600 m. They are generally moderately well drained with gradational texture profiles and moderate permeability. Profiles are characterised by dark-coloured silty clay loam surface layers and brownish yellow or yellowish red clayey subsoils usually with grey or red mottles. Stone content is variable but profiles on steep slopes are typically stony. Chemical data are not available but the soils are likely to have strongly acid surface and subsoil layers with medium or high organic C and total P.

Under mixed forest or rainforest (1 900 ha, <1%)

The vegetation is mainly rainforest or *Eucalyptus delegatensis*-dominated mixed forest with *Nothofagus cunninghamii* and/or *Atherosperma moschatum* and *Acacia dealbata* over a ferny understorey. These soils occur on rolling and steep hills and mountains at elevations between about 500 and 700 m. They are generally well drained with gradational texture profiles and moderate permeability. Profiles are characterised by dark-coloured loamy surface layers overlying yellowish-brown clayey subsoils usually with weak strength. Profiles are often stony, particularly on steep slopes. Chemical data are not available but the soils are likely to have very strongly acid surface and subsoil layers with high levels of organic C and total P.

Soils on dolerite

Under dry sclerophyll forest (88 500 ha, 17%)

These soils occur on undulating, rolling and steep hill slopes at elevations between about 50 and 600 m. They include imperfectly drained soils with texture-contrast profiles and moderately well-drained soils with gradational texture profiles. Soils with imperfect drainage occur widely in lower rainfall areas under grassy, open forest dominated by *Eucalyptus amygdalina*. *Acacia dealbata* and *Bursaria spinosa* commonly occur in the understorey over a diverse ground layer that usually includes *Acrotriche serrulata* and grasses including *Poa* spp. *Eucalyptus viminalis* sometimes occurs as a subdominant. Profiles are characterised by dark greyish-brown loam or clay loam surface layers overlying pale-coloured clay loams usually with many rounded ferromanganiferous gravels. Beneath is a dark brown and grey mottled tough clay which shows marked shrink-swell properties. Many stones or boulders usually occur throughout the profile. Permeability is assessed as slow to very slow. Chemical analysis shows that surface layers

are moderately acid with medium levels of organic C and low to medium levels of total P. Subsoils are moderately acid with low levels of both organic C and total P.

Moderately well-drained soils have profiles characterised by brown clay loam surface layers overlying red clayey subsoils. Stone content is variable but profiles typically have many to abundant stones or boulders throughout. Ferromanganiferous gravels often occur in the surface or subsurface layers. Permeability is assessed as moderate. On these soils the vegetation is shrubby dry sclerophyll forest dominated by *Eucalyptus obliqua* and/or *E. amygdalina* with *E. viminalis* sometimes present. Common understorey species include *Acacia genistifolia*, *A. myrtifolia*, *Banksia marginata*, *Lomatia tinctoria*, *Pultenaea gunnii*, *Lomandra longifolia* and *Diplarrena moraea*. Chemical analysis shows that surface layers are moderately acid with low levels of both organic C and total P. Subsoils are strongly acid with low levels of organic C and total P.

Under wet sclerophyll forest (13 600 ha, 3%)

Mainly *Eucalyptus delegatensis* or *E. regnans*-dominated wet sclerophyll forest with *E. obliqua* and/or *E. viminalis* sometimes present. *Acacia melanoxylon*, *Zieria arborescens* and *Notelaea ligustrina* are often present with understorey species that may include *Coprosma quadrifida* and ferns such as *Dicksonia antarctica*. These soils occur on undulating, rolling and steep hill and mountain slopes at elevations between about 300 and 700 m. They are generally well drained with gradational texture profiles and moderate permeability. Soil profiles are characterised by dark-coloured loam or clay loam surface layers overlying red clayey subsoils. Stoniness is highly variable but profiles typically have many to abundant stones or boulders throughout. Chemically the soils have moderately acid surface layers with medium levels of both total P and organic C. Subsoils are slightly acid with medium levels of total P and low organic C.

Under mixed forest or rainforest (4 900 ha, 1%)

Mainly mixed forest with *Eucalyptus delegatensis*, *Nothofagus cunninghamii*, *Acacia dealbata*, *Zieria arborescens*, *Bedfordia salicina*, *Olearia argophylla* over *Coprosma hirtella*, *Polystichum proliferum* and *Blechnum wattsii* amongst other species. This grades into *Nothofagus cunninghamii* and *Leptospermum lanigerum*-dominated low forest at higher altitudes. These have understorey species such as *Tasmannia lanceolata*, *Olearia phlogopappa*, *Telopea truncata*, *Orites revoluta* and *Oxylobium ellipticum*. These soils occur on rolling and steep mountain slopes at elevations between about 600 and 1 100 m. They are generally well drained with gradational texture profiles and moderate permeability. Under mixed forest soil profiles are characterised by dark brown, stony loam to clay loam surface layers overlying strong brown, stony clay loam subsoils usually with weak strength. Many to abundant stones or boulders occur throughout. Chemically the soils have strongly acid

Fig. 2. Representative sequence of forest soils on undulating and rolling dolerite in north-east Tasmania showing soil features in relation to vegetation, mean annual rainfall and altitude.

VEGETATION

Open dry sclerophyll forest

Shrubby dry sclerophyll forest

Wet sclerophyll forest

Mixed forest

Mid to high altitude dry sclerophyll forest

Alpine scrub and herb field

RAINFALL AND ALTITUDE

Mean annual rainfall (mm/yr)	600-1000	800-1000	1000-1400	1400-1600	800-1200	>1400
Altitude (m)	50-400	100-600	300-700	600-1100	600-1100	1100-1570

SOIL TEXTURE

Texture in soil profile	Texture contrast profile: Loam over clay	Gradational or texture contrast profiles: Clay loam or loam over clay	Gradational texture profile: Clay loam over clay	Gradational texture profile: Loam over clay loam	Gradational texture profile: Loam over clay loam	Gradational texture profile: Peat over loam over clay loam with iron pan

ORGANIC CARBON AND TOTAL PHOSPHORUS IN 0-10 cm

Organic carbon %	Medium (2-5)	Low (<2)	Medium (>5)	Low/medium (<2/2-5)	High (>5)	High (>5)
Total Phosphorus (ppm)	Low/medium (<100/100-250)	Low (<100)	Medium (100-250)	High (<250)	High (>250)	High (>250)

surface layers with high levels of total P and medium organic C. Subsoils are very strongly acid with low organic C and high total P. Phosphorus retention is very high throughout the profile.

At higher elevations between about 800 and 1 100 m subalpine rainforest often occurs. The soils here are characterised by thick, dark reddish-brown organic loam surface layers overlying brown sandy loam subsoils. Depth and stone content are highly variable, but profiles are typically stony and shallow (<50 cm). The soils commonly occur in association with extensive

unvegetated scree slopes of dolerite boulders. Chemical data are unavailable but the soils are likely to have high levels of both organic C and total P.

Under mid- to high-altitude dry sclerophyll forest (31 000 ha, 6%)

The forest is relatively open *Eucalyptus delegatensis* (occasionally occurring with *E. dalrympleana*) with the shrub layer dominated by species such as *Bedfordia salicina, Lomatia tinctoria, Pultenaea juniperina* and *Exocarpos cupressiformis*. These soils occur on undulating, rolling and steep mountain slopes at elevations between 600 and 1 100 m. They are generally well drained with gradational texture profiles and moderate permeability. Profiles are characterised by dark-coloured loamy surface layers overlying red or brown clay loam or clayey subsoils usually with weak strength. Stone content is variable but typically many to abundant stones or boulders occur throughout. Chemically, surface layers are strongly acid with high levels of total P and low to medium organic C. Subsoils are moderately acid with high total P and low organic C.

Under alpine scrub and herbfield

Alpine scrub is dominated by species such as *Helichrysum backhousii, Richea scoparia, Orites acicularis, Epacris serpyllifolia* and *Baeckea gunniana* while species such as *Poa gunnii, Empodisma minus, Astelia alpina* and *Oreobolus distichus* become more prevalent in the herbfield. These soils occur on undulating, rolling and steep mountain slopes at elevations above about 1 100 m. They include very shallow soils developed on dolerite bedrock and deep (>1m) soils formed in thick dolerite slope deposits. Soil profiles developed in thick slope deposits are characterised by peaty surface layers overlying dark-coloured loamy mineral layers which in turn overlie pale yellow and brown clay loam subsoils with weak strength. Thin iron pans often occur in subsoils. Gravels, stones and boulders are predominant throughout the profile. Rock outcrop and unvegetated boulder fields are widespread in this alpine environment. Chemical data are not available but the soils are likely to have very high organic C and medium to high total P levels in surface layers. Subsoils are likely to have low levels of organic C and medium total P.

Soils on basalt

Under dry sclerophyll forest (2 100 ha, <1%)

The forest is often dominated by *Eucalyptus viminalis* with *E. obliqua* also occasionally present. Understorey species often include *Acacia melanoxylon, Exocarpos cupressiformis* and *Bursaria spinosa*. These soils occur on undulating and rolling low hills at elevations between about 60 and 300 m. They include rapidly drained, highly permeable stony soils under open forest and well drained,

moderately permeable soils under moist sclerophyll forest. Rapidly drained soils are characterised by dark reddish sandy loam layers overlying red sandy clay loam subsoils. Abundant stones and boulders occur throughout. Well drained soils have dark reddish-brown clay loam surface layers overlying red light clay subsoils. Few stones or boulders occur throughout the profile. Chemical data are not available but the soils are likely to have moderately acid surface and subsoil layers with high levels of total P and moderate to high organic C.

Under wet sclerophyll forest and mixed forest (240 ha, <1%)

The forest is dominated by *Eucalyptus regnans* and/or *E. obliqua* or occasionally *E. dalrympleana* with understoreys ranging from wet sclerophyll to rainforest. These soils occur on rolling and steep hills at elevations between about 300 and 800 m. They are well drained with gradational texture profiles and moderate permeability. Soil profiles are characterised by dark-coloured clay loam surface layers overlying reddish-brown light clay subsoils. Sparse to common gravels/stones occur throughout the profile. Chemically the soils have very strongly acid surface layers with very high levels of total P and organic C. Subsoils are strongly acid with very high total P and medium to high organic C. Phosphorus retention is high in surface layers and very high in subsoils.

Soils on Quaternary alluvium and aeolian sands

These soils are highly varied and include a wide range of environmental features. Landforms include recent alluvial floodplains and coastal aeolian dunes and older Pleistocene terraces and dunes. Drainage varies from rapidly draining aeolian sands and stony alluvium to very poorly drained peaty depressions.

Under sedgeland-heath and wet scrub

Vegetation ranges from sedgeland-heath to wet scrub with species such as *Gymnoschoenus sphaerocephalus, Melaleuca squamea, M. squarrosa, Leptospermum lanigerum* and *Banera rubioides* usually present. *Eucalyptus amygdalina* and *E. ovata* vary in frequency of occurrence, sometimes forming sedgey open dry sclerophyll forest. These soils occur on flat to undulating alluvial depressions or flats generally associated with drainage lines and watercourses. They are poorly to very poorly drained with organic or gradational texture profiles and slow to very slow permeability. Soil profiles are characterised by black peaty layers of variable thickness overlying dark-coloured sandy loam layers which in turn overlie light grey sandy or clayey subsoils. Yellow-brown or red mottling is often prominent in upper subsoils. Chemically the soils have very strongly acid surface layers with high or very high organic C and low to medium total P. Subsoils are very strongly acid with low levels of both organic C and total P.

Under dry sclerophyll forest (<1%)

The forest often includes *Eucalyptus amygdalina* with *Allocasuarina littoralis*, *Banksia marginata*, *Acacia terminalis* and *Leptospermum scoparium*. These soils occur mainly on flat to undulating alluvial terraces although some are formed in recent alluvium on floodplains and footslopes of hills. They are generally well drained with uniform or gradational texture profiles and moderate permeability. Soil profiles are characterised by dark-coloured loamy surface layers overlying yellowish-brown clay loam subsoils. Stones commonly occur throughout the profile. Soils formed in recent alluvium typically are rapidly draining with high permeability and are sandy and stony throughout the profile. Chemical data are not available but the soils are likely to have strongly acid surface layers with medium to high levels of organic C and total P. Soils formed in recent alluvium are likely to have low levels of both organic C and total P in surface layers.

Under wet sclerophyll forest (<1%)

These soils occur mainly on flat to undulating alluvial terraces and to a minor extent on recent floodplains. They are generally well drained with gradational texture profiles and moderate permeability. Soil profiles are characterised by dark-coloured loamy surface layers overlying brown or reddish-brown clay loams. Stones commonly occur throughout the profile. Chemical data are not available but the soils are likely to have high levels of both organic C and total P in surface layers.

Under low coastal woodland and scrub (<1%)

Coastal scrub communities are often dominated by *Banksia marginata* and *Monotoca elliptica* with *Allocasuarina littoralis*, *Acacia sophorae*, *Eucalyptus amygdalina* and *E. viminalis* common. These soils occur on gently undulating to rolling and sometimes steep coastal sand dunes. They include very recent aeolian sands adjacent to the coast and older sands inland. The soils are typically rapidly draining with uniform coarse textured profiles and high permeability. On stabilised dunes soil profiles are characterised by dark-coloured sandy surface layers overlying deep bleached loose sands which in turn overlie yellowish-brown sands. On the lower-lying sand plains poorly drained sandy soils with cemented humic-iron pans and very poorly drained organic soils with thick peaty layers predominate. Chemical data are unavailable but the rapidly draining sandy soils are likely to have low levels of both organic C and total P in surface layers and subsoils.

Soil constraints for plantation forestry

The soils have been assessed and classified in table 2 for both site productivity and land suitability for plantations using the methodology of Laffan (1993).

Four classes of site productivity are defined in terms of peak mean annual volume increment (MAI) of forest growth expressed as m³/ha/yr. They range from high productivity (MAI >20) in Productivity Class 1 to very low productivity (MAI >10) in Productivity Class 4. The ratings of MAI apply primarily to the main commercial eucalypts (*E. globulus* and *E. nitens*) currently used in plantations and are less precise for radiata pine. Productivity class is assessed from six land factors: temperature regime, moisture availability, drainage, rooting conditions, nutrient availability and nutrient retention.

Land suitability refers to sustainable use and it takes account of land degradation hazards and management limitations as well as the productive capacity of the land. It does not include other hazards such as forest fire, pests and diseases, nor does it consider wood quality or socio-economic factors. Four classes of land suitability are defined ranging from highly suitable (Suitability Class 1) to unsuitable (Suitability Class 4). Class 1 has no significant limitations for plantation productivity or for sustainable use in plantation forestry whereas classes 2 to 4 have significant limitations of increasing severity affecting management and/or degradation and/or productivity potential.

Ten land factors are used to determine suitability class. They include the six factors used to assess productivity class together with four other land factors affecting plantation mangement and land degradation. These are; trafficability, flood hazard, erosion hazard and landslide hazard. The assessment criteria and ratings for these factors are given in Laffan (1993). The most limiting land factor determines the suitability class along with the subclass notation. Soils occurring on steep (>30%) slopes are classified as being unsuitable (Class 4) for plantations because of very severe constraints of trafficability.

Discussion and conclusions

The twenty soil-physiographic units described above show marked differences in morphological and chemical soil properties. They reflect significant variations in the five soil-forming factors: parent material, climate, biota, topography and time.

The transition from dry sclerophyll forest to wet sclerophyll forest to mixed forest and rainforest corresponds to a marked increase in mean annual rainfall usually in association with increasing elevation. This effect is shown most clearly by the higher levels of organic matter and relatively weak strength in soils under mixed forest or rainforest compared to much lower organic matter and firmer strength in soils under dry forest.

The predominance of texture-contrast soils on easy slopes under dry forest compared to mainly gradational soils under wet forests reflects a variety of factors including

Table 2. Classification of site productivity and land suitability for soil-physiographic units in northeast Tasmania.

Soil-physiographic Unit	Site Productivity Class[1]	Land Suitability Class and Subclass[2]
Soils on granite		
under dry sclerophyll forest	3-4	3mrl-4m, 4t
under wet sclerophyll forest	1	1-4t
under mixed forest or rainforest	1-4	1-4p, 4t
Soils on sandstone		
under dry sclerophyll forest	3	3mrl-4t
under wet sclerophyll forest	1	1-4t
under mixed forest or rainforest	1-4	1-4p, 4pt
Soils on mudstone		
under dry sclerophyll forest	3	3ml-4t
under wet sclerophyll forest	1	1-4t
under mixed forest or rainforest	1	1-4t
Soils on dolerite		
under dry sclerophyll forest	3	3mrl-4t
under wet sclerophyll forest	1-3	1-3rt, 4t
under mixed forest or rainforest	1-3	1-3rt,4t
under mid- to high-altitude dry sclerophyll forest	3-4	3mlt-4pt
under alpine scrub and herbfield	4	4p-4pt
Soils on basalt		
under dry sclerophyll forest	1-3/4	1-3/4mrt
under wet sclerophyll forest and mixed forest	1	1-4t
Soils on Quaternary alluvium and aeolian sands		
under sedgeland-heath and wet scrub	3-4	3drt-4drt
under dry sclerophyll forest	3-4	3mrl-4m
under wet sclerophyll forest	1	1
under coastal low woodland and scrub	1-4	1-4m, 4drt

[1]   Class 1 = high productivity   Class 2 = medium productivity
       Class 3 = low productivity   Class 4 = very low productivity

[2]   Class 1 = highly suitable   Class 2 = moderately suitable
       Class 3 = marginally suitable   Class 4 = unsuitable

Subclasses refer to limiting land factors as follows:
p = temperature regime, m = moisture availability, d = drainage
r = rooting conditions, l = nutrient availability, t = trafficability

marked differences in age of the soils, in the duration and intensity of dry seasons and in the levels of biological activity. Low levels of total P occurring in most soils under dry forests is thought to result mainly from the older and more strongly weathered nature of their parent materials. Higher levels of total P in soils under wet forests is attributed to the younger and less weathered nature of their parent materials and to more effective cycling and accumulation of organic matter.

The assessment and classification of soil constraints for plantation forestry shows that soils with the best potential for plantation growth (Productivity Class 1) occur preferentially at lower elevations under wet sclerophyll and mixed forests or rainforests. Characteristically these soils have gradational texture profiles, are well or moderately well drained, deep (>80 cm) with relatively few stones and have medium or high levels of organic matter and total P. At higher elevations soils under wet forest are constrained by low temperatures which adversely affect plantation growth. Under other types of native vegetation the soils have severe or very severe

constraints for plantation growth. They are classified as low or very low productivity (Productivity Class 3 and 4). Soils that are highly suitable for plantations (Suitability Class 1) are restricted to soils with high productivity (Productivity Class 1) occurring on slopes below 30%.

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Managing Land and Wildlife in Northeast Tasmania

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Abstract

The Department of Environment and Land Management, through the Parks and Wildlife Service, has the responsibility for managing a diverse range of lands in northeast Tasmania. The management of these lands is complex and often deals with conflicting uses which impact on the biogeography of surrounding lands. This presentation looks at the lands managed by the Parks and Wildlife Service, the management practices and uses (both past and present) and their impacts, and possible solutions to management problems. Specifically discussed are: Native Point Nature Reserve, Egg Island Point Coastal Reserve, Low Head Coastal Reserve, W.A.G. Walker Rhododendron Reserve, Weymouth Coastal Reserve, the Bridport foreshore, Granite Point Coastal Reserve, Bridport Wildflower Reserve, Waterhouse Protceted Area, the South Mt Cameron area, Mt William National Park, Ansons Bay Coastal Reserve, Ansons River Reserve, Ben Lomond National Park and Mt Barrow State Reserve. Most of the Department's conservation effort in the Northeast is focussed on the activities of area users. Over-use or inappropriate use leads to management problems and habitat loss. The provision and maintenance of facilities to cater for visitors, shack owners, lease and licence holders make up the bulk of the management effort in Crown reserves in the Northeast.

Effects of Repeated Fires on Dry Sclerophyll (*E. sieberi*) Forests in Northeast Tasmania

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Abstract

Eucalyptus sieberi forests occur on infertile substrates in the low-rainfall areas of northeast Tasmania. These forests have been subjected to a fire regime of regular repeated fires, at least since European settlement of Tasmania. Floristic, edaphic and fuel load data were collected from a range of sites across the range of *E. sieberi*. The *E. sieberi* forests are currently subject to a fuel reduction burning program with a seven year return cycle. Analysis of the fuel load data suggests that fuels in these forests reach equilibrium between 15 and 20 years after fire. If nutrient cycling and invertebrate populations require similar time intervals to re-establish following fire, then the fire return interval of seven years is likely to have detrimental effects on these forests. Unfortunately there are no sites of sufficient age (i.e., unburnt for greater than 15 years) available for comparative studies. In order to gain a better understanding of the long-term dynamics of these forests, a series of permanent transects has been established.

Introduction

Since 1970 Forestry Tasmania has advocated the use of fuel reduction burning in the dry forests of east Tasmania, on a 7 year cycle. In the case of the *Eucalyptus sieberi* forests, this has resulted in a regime of frequent regular fires being applied to an area which had been subjected to a similar regime, largely through arson, for many years. The *E. sieberi* forests have been intensively used by Europeans since the early days of settlement. The trees split readily and provide durable fenceposts, firewood with excellent burning qualities and high-quality sawn timber. Minerals, predominantly gold and tin, were discovered in these areas very early in the history of European settlement and extensive water races were cut through the forests to provide sufficient water for alluvial extraction of the minerals.

This project was established to investigate the impact that repeated fuel reduction burning is having on the *E. sieberi* forests. In particular the project was designed to address four questions. Does fuel reduction burning reduce fuels and if so for how long? Does fuel reduction burning affect fire behaviour? Does fuel reduction burning change the floristics and if so, how, and does fuel reduction burning affect the structure of the forest and if so, how?

Methods

The study area

The *E. sieberi* forests of east Tasmania occur in a broken band on the northern East Coast (fig. 1). The *E. sieberi* forests occur on three different substrates: Jurassic dolerite, Devonian granite, and fine-grained Ordovician sediments colloquially known as Mathinna Beds. Only a small area of *E. sieberi* forest occurs on dolerite and these forests are not considered any further here. The soils

Fig.1. The *Eucalyptus sieberi* forests of east Tasmania

derived from the granite and Mathinna Bed parent materials within the range of *E. sieberi* are infertile (Davies & Nielsen 1987). On granite substrates the soils are largely gravel. On Mathinna Bed substrates the soils are very fine-grained loams with a high gravel content. Topographic relief on the two different substrates is markedly different. In Mathinna Bed areas ridges are sharp and slopes are steep, with deeply incised creeklines. Aspect in these areas has a marked effect on the nature of the vegetation. In the granite areas the relief is considerably more subdued. Slopes are gentle and drainage lines are commonly broad, although the upper reaches of some drainage lines around the few peaks in the area can be steep. In the granite country the effect of aspect is less significant than in the Mathinna Bed areas.

The climate on the northeast Tasmanian coast is mild with very little difference between the winter and summer

maximum temperatures (Gentilli 1972). Rainfall is around 800 mm per annum and rainfall occurrence is erratic. There is no pronounced winter or summer peak; however, rainfall is often associated with intense low-pressure systems which can produce large amounts of rain in quite short periods (up to 150 mm in 48 hours). This is often followed by long periods in which there is very little rainfall.

Floristic sampling

Floristic lists and TASFORHAB structural profiles (Peters 1984) were collected during the establishment of the permanent transects and from all the sites at which fuel loads were sampled. Profiles were also collected opportunistically from other sites which were examined for their suitability for other studies but not used. A set of profiles was also collected from the coastal *E. sieberi* forests which were not otherwise examined. Data from 255 TASFORHAB plots were entered into the ecological database, DECODA (Minchin 1990). This package was used to prepare outputs for classification and ordination. DECODA was also used to derive species richness and diversity.

Fuel load sampling

Fuel loads were assessed in detail at 54 sites. Fuels were assessed by taking 15 x 0.1 m² samples of the fuel load (samples were collected using a 316 x 316 mm wooden square) at each site. A random start point was established by throwing a notebook behind the recorder. From the start point a line transect was established parallel to the contour and fuel samples were taken every 10 m along the transect. The transect was laid out so as to remain wholly within a single vegetation type. If the transect ran into a different type a second line was established parallel to the first and either above or below the original line. At each point the wooden square was laid on the ground with one side parallel to the tape, and all the fine fuel contained within an imaginary column in and up to 1 m above the square was collected (fine fuels are defined (Luke & McArthur 1978) as organic material less than 6 mm in diameter). Fifteen samples were collected from each site. As fuels throughout the *E. sieberi* forests are very largely composed of dead material, live and dead fuels were not separated, although both (where both were present) were collected.

The fuel samples were oven dried at 80°C for 24 hours. Gravel, rocks and fine material below 0.7 mm were removed from the sample, which was then weighed.

The fire age of each site was determined both from Forestry Tasmania records and from on-site sampling. *Banksia marginata* is reputed to grow in annual increments and counting the nodes is believed to provide a reasonable estimate of the time since the last fire, where there are cohorts of *Banksia marginata* individuals all having the same node count (Brown & Podger 1982). Most of the study sites have been fuel reduction burnt within the last 10 years and the *Banksia* ages could be compared to the known last fire date.

The fuel load was modelled using a modified form of Walker's (1981) model:

$$W^t = W^{ss}(1-e^{-kt}),$$

where

W^t = weight at time t (years after fire)

W^{ss} = a constant equal to the amount of fuel under steady state conditions (tonnes per ha)

k = a constant equal to the proportion of litter that decomposes

t = time since fire (years).

Fensham (1992) modified the model as shown below to allow for the fact that immediately following fire there is a certain amount of unburnt fuel left on the site:

$$W^t = W^{ss}(1-e^{-kt}) + 1.92(e^{-kt}).$$

Fensham (1992) tested the goodness of fit to his data of this model versus the unmodified model and found the modified function to perform better for 6 of 8 vegetation types.

Results

Floristics

Throughout the range of *E. sieberi* the forests are largely monospecific and remarkably similar. On the driest (north-facing) slopes *E. sieberi* forms pure stands. *E. viminalis* may also be present on the lowest slopes and on more south-facing slopes. *E. amygdalina* may be present as a subdominant on granite sites. *E. sieberi* is replaced by *E. obliqua* on more mesic sites.

The understorey is simple. Large shrubs are rare with the exception of *Allocasuarina littoralis* which can form dense thickets but which is more often found as scattered shrubs. Small shrubs are invariably sparse. On granite sites the dominant understorey species are *Gonocarpus tetragynus*, *Pteridium esculentum*, *A. littoralis*, *Goodenia*
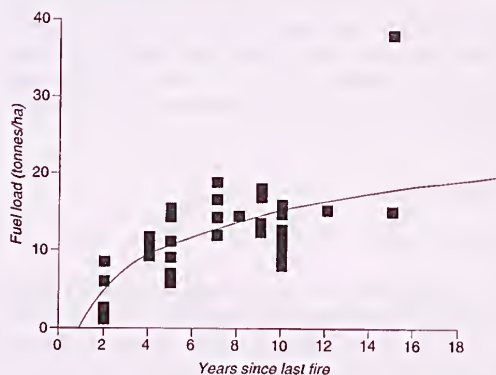

Fig. 2. Fuel loads in *E. sieberi* forest against years since the last fire.

lanata, Hibbertia empetrifolia, Lepidosperma concavum, L. laterale, Lomatia tinctoria, Epacris impressa, Aotus ericoides and *Banksia marginata*. On Mathinna Bed sites the dominant understorey species are *G. tetragynus, P. esculentum, A. littoralis, G. lanata, Tetratheca labillardieri, Pultenaea gunnii* and *Acacia dealbata.*

On granite sites, there are 37 species which occur on more than 20% of the sites. Of these species, 29 are vegetative resprouters, (and 20 of the commonest 23 are vegetative resprouters). On Mathinna Bed sites, 36 species occur on more than 20% of sites. Of these, 26 are vegetative reproducers, (and all of the 10 most abundant species are vegetative resprouters).

Fuel loads

Fensham's model using the whole data set gave an estimate of W^{ss} of 49.16 tonnes per hectare, with a k value of 0.033 (R^2 of 0.577). Removing the outlying data point (top right in fig. 2) gave an estimate of W^{ss} of 15.17 t/ha, with a k value of 0.225 (R^2 of 0.467). Fox et al. (1979), recalculated the data of Van Loon (1977) and found the steady state fuel load in *E. sieberi* forests in the Blue Mountains of New South Wales to be 14.8 t/ha, which compares well with the second model above.

Discussion

Floristics

Analysis of the floristic data indicates that the species which occur in the understorey of *E. sieberi* forests are predominantly those which are able to reproduce vegetatively. Species richness varied from 13 (driest north facing slopes on Mathinna Bed substrates) to 26 (coastal sites). Similar communities in Victoria (Forbes et al. 1982) have species richness values which range from 33 to 57 (these communities in Victoria are defined as those in which *E. sieberi* is present in at least 50% of the quadrats sampled). There is too little information available to make a direct comparison of the proportion of vegetative reproducers to obligate seeders in the Victorian forests and it is possible that the greater floristic richness in the Victorian forests is determined by a number of factors apart from fire history. Nonetheless it is interesting that the Victorian *E. sieberi* forests show a consistently higher species richness than their Tasmanian counterparts.

Fuel loads

From figure 2 it is apparent that the accumulation of fuel in *E. sieberi* forests is typical of eucalypt forests in that the fuel load shows a rapid early accumulation rate which then tends to level off. The notable exception in this case is the site at top right of the figure which has an exceptionally high fuel load. This site, which has not been burnt for at least 15 years, has a near-closed understorey dominated by *Allocasuarina littoralis*. The fuel load is comprised very largely of *Allocasuarina* needles which in

places formed a layer over 15 cm deep. This site was also interesting as it was the only site at which an active and diverse invertebrate fauna was observed.

If it weren't for the site at top right, it would appear from the graph to be a reasonable assumption that fuel loads in *E. sieberi* forests reach a steady state of around 15 to 20 tonnes per hectare at 15 to 20 years after a fire. However the exceptional site also points to the possibility that sites carrying *Allocasuarina littoralis* can carry much heavier fuel loads. *A. littoralis* is ubiquitous in *E. sieberi* forests and therefore the possibility of fuel loads exceeding 25 t/ha (in the long-term absence of fire) cannot be discounted.

Both Hutson and Veitch (1985) and Birk and Simpson (1980) indicate that deriving decomposition constants for sites which have yet to reach steady-state conditions is statistically suspect. The model only derives the curved portion of the fuel accumulation curve, which is then extrapolated forward in time to indicate the steady-state fuel load. Small variations in the litterfall rate can lead to larger variations in the steady-state fuel load. In the present case, where the model indicates that steady-state fuels are reached between 15 and 20 years after fire, but where the collected data is from sites which have predominantly been burnt within the last ten years, the results must be interpreted with caution.

Conclusions

We posed four questions at the start of this paper. Does fuel reduction burning reduce fuels and if so for how long? Does fuel reduction burning affect fire behaviour? Does fuel reduction burning change the floristics and if so, how, and does fuel reduction burning affect the structure of the forest and if so, how?

Fuel reduction burning does reduce fuels. Figure 2 shows that sites recently burnt have significantly reduced fuels. The figure also shows that fuels can reach 'unmanageable' levels (i.e., in excess of 12 t/ha) in as little as five years. The period of protection offered by fuel reduction burning can thus be as short as three years, although it is longer than this at many sites. Fuel reduction burning will therefore have an impact on fire behaviour but only on sites which have been fuel reduced within the last five years.

The impact of fuel reduction burning on the floristics and structure of these forests is more difficult to quantify. The understoreys throughout the range of *E. sieberi* are dominated by species which reproduce vegetatively after fire; species which are obligate seed regenerators are less common and generally restricted to more mesic sites. With an average fire return period of less than ten years, a secondary shrub layer rarely develops, although *A. littoralis* can be prominent in the understorey. There are four sites known, all less than 1 ha in size, with a more diverse understorey including a number of less common

species such as *Eriostemon virgatus* and *Leucopogon ericoides*, which are obligate seed regenerators. If it is the case that these sites are indicative of the less frequently burnt environment, then the floristics and structure of the *E. sieberi* forests have been greatly simplified by the past fire regime. However it is not possible to accurately quantify the fire history of any of the sites in the Northeast so such statements need to be read with caution.

The fuel load data indicates that steady-state fuel loads are reached around 15 to 20 years after fire. If nutrient cycling and invertebrate populations require similar time intervals to re-establish after fire then a fire return interval of seven years is likely to have a detrimental effect on these forests. Studies on nutrient cycling in the *E. sieberi* forests have not been undertaken and studies on invertebrate populations are in their infancy. Further work in these areas will greatly benefit our understanding and management of these forests.

Because of the difficulty of assessing the impact of the past fire regime on the vegetation of the Northeast, a series of permanent transects, recording the present nature of the vegetation, has been established in the region and will be monitored through time. These transects will hopefully demonstrate any future changes to the vegetation of this area.

Hypothesising about the nature and impact of the past fire regime is interesting but will always be speculative, because we cannot be certain of the regimes which prevailed prior to European settlement. The more pertinent question that needs to be addressed is 'How do we wish to manage these forests now?' Fuel loads, particularly around identified assets such as plantations and towns, clearly must be managed in such a way as to provide a point of control of wildfires. But the imposition of a blanket fire regime over the whole range of *E. sieberi* in Tasmania will lead to the creation of a large area with very similar and simple vegetation. Applying a regime of frequent low-intensity fires to specified areas for fire management purposes and also allowing other areas to remain unburnt for varying periods of time will create a more diverse regional vegetation pattern. Long term *in situ* monitoring is essential to follow changes in the vegetation and fire-free control areas also need to be established.

Acknowledgements

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Agricultural Soils in Northeast Tasmania

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Abstract

Variable is the word which aptly describes the wide range of soil types used for agriculture in northeast Tasmania. This variability is derived from the complex nature of the geology and landforms found in the region. Soils range from deep windblown sands on the northern coastal plains through to arguably some of Australia's most productive soils, the krasnozems around Scottsdale and Branxholm. However the majority of soils in the region are duplex or gradational soils formed on granite and the Mathinna Beds. The krasnozems and some granitic soils are used for vegetable cropping, particularly around Scottsdale. On initial clearing the krasnozems are quite fertile, physically well-structured, well-drained gradational soils. Their highly productive capacity also makes them ideal for dairy production. The remaining soils are generally low in fertility, have a low pH and, apart from the coastal sands, have low permeability. Although these soils are low in productivity, their location in terms of climatic conditions means that they produce valuable feed particularly during winter months. Soil and land degradation problems associated with soils within the region include wind, sheet and rill erosion; nutrient decline; structural decline; waterlogging; and salinity.

Introduction

This paper outlines the general distribution, some properties and the limitations to use of the main soils used for agriculture in the Northeast of Tasmania. Some soil types are not covered because of the small area they cover. Detailed soil map coverage of the Northeast is limited, with only a small number of localised soil maps having been published. These include those of Hubble (1946), Stephens and Cane (1937), Dimmock (1957, 1960) and Nicolls (1957). The main reference for general soil type information within the region is the publication *Land Systems of Tasmania - Region 4* published by the Tasmanian Department of Agriculture (Pinkard 1980). This report and its accompanying 1:100 000 scale maps outline the land systems within the region. Whilst the report does not contain detailed soil maps for any land system, the land system descriptions contain details on the range of soils and some of their properties for each land system. As it covers the entire region, the report provides the most extensive description of soils found within the Northeast. Information on the land capability of part of the region (also including descriptions of soils), is contained in the publication by Noble (1991) titled *Land Capability Survey - Pipers Report*.

Distribution, attributes and constraints of soils

The soils of the Northeast are very diverse and variable in terms of occurrence, colour, depth, structure, texture, fertility and constraints to use. This is largely due to the complex geologic pattern, and to a lesser extent the climatic pattern, found within the region. Soil types used for agriculture in the region occupy less than one third of the total area, with the other major land uses being forestry and nature conservation. The principal soil types used for agriculture are sandy soils; alluvial soils; soils on sedimentary rocks such as mudstone, siltstone and sandstone; soils on igneous rocks such as dolerite and granite; and soils on basalt (krasnozems).

Sandy Soils

1. Sandy soils of the coastal areas

The soils found in the northern coastal areas of the region are principally sandy soils varying in colour from light to dark grey, located between the coastal dunes and the low foothills of the northeast Tasmanian ranges. These sandy soils contain variable levels of organic matter in the surface and commonly have a black and brown organic hardpan at anywhere between 40 and 100 cm depth. This hardpan and the variable topography of the area means that many of these soils are often waterlogged in the winter months, particularly where adequate surface drainage is not provided. These sandy soils have a low pH down the profile, are low in available nutrients and are particularly prone to wind erosion when denuded or overgrazed. Scattered along the coastal plain are stabilised inland sand dunes which consist of a variable depth of light grey sand over deep yellow sand. These sandy soils of the coastal areas are used for grazing of sheep and cattle on improved pasture. The favourable climate of the area (warm and moist) means that these areas are valuable for pasture production during winter months when more inland areas are restricted by colder temperatures. These sandy soils, if left without vegetation cover, are particularly prone to wind erosion. Some of the lower-lying parts of the coastal areas are also affected by dryland salinity. The poor surface drainage patterns of the areas behind the coastal dunes, combined with the precipitation of salt from salt-laden rain means that, unless adequate surface drainage is installed, there is a build up of salt in the surface of these soils. This appears

to be an increasing problem.

2. Other sandy soils

Throughout the Northeast there are a number of areas of grey to brown sandy soils formed on Quaternary and Tertiary deposits, particularly in the western part of the region. These are deeper soils with a loamy sand to sandy loam surface overlying a clay subsoil at depth. Soil fertility and pH are generally low and the poor soil structure and lower organic matter levels render these soils generally unsuitable for cropping. They are used extensively for grazing of improved pasture, although waterlogging during the winter months is often a problem on these soils. If left bare the sandy surface is particularly prone to wind erosion.

Alluvial soils

Alluvial soils have formed on the floodplains of the major streams and rivers in the region, such as along the Ringarooma, Brid, Georges, North Esk and South Esk Rivers. These soils vary from sandy and silty loams to heavy clays depending on the sediment source and stream dynamics. They are often deep and comparatively fertile, and therefore are commonly used for cropping in areas where climatic conditions allow. However because of their low-lying position in the landscape, the use of these soils for cropping is often restricted by frost incidence and flooding risk. In addition the heavier soils and those with clay subsoils are prone to waterlogging. They are generally highly productive under improved pasture for grazing of sheep, beef and dairy cattle. In some areas these alluvial soils are gravelly or stony in the surface, reducing their agricultural use to grazing of improved pasture.

Soils on mudstones, siltstones and sandstones

The major occurrence of these soils is on the mudstones, siltstones and sandstones of the Mathinna Bed series. They are generally either duplex with a sandy loam surface overlaying a clay subsoil, or gradational with a sandy clay loam to clay loam surface passing gradually into heavy clay subsoils. The duplex profiles are more typical under lower rainfalls close to the coast, while the gradational profiles are dominant in the higher inland country (Nicolls et al. 1965). Constraints to use for agriculture include their inherent low pH and fertility and their proneness to erosion, particularly water erosion, as they often occur on sloping land. They are used principally for grazing of sheep and cattle on improved pasture.

Soils on dolerite

Soils on dolerite are scattered throughout the Northeast, although their main occurrence is in the western part of the region extending from the coast to the southern boundary. These soils are variable in terms of soil depth and the amount of stones and boulders present throughout the soil profile. They are both gradational and duplex soils, often having shallow clay loam or loam topsoils over subsoils of light or heavy clay. The main limitation to agricultural use (particularly cropping) is the presence of stone and boulders in the surface. They are used extensively for grazing of sheep and cattle on both improved and native pastures. Waterlogging is a problem during the winter months because of low soil permeability.

Soils on granite

Granite and granordiorite-based soils are common throughout the Northeast, from the low foothills in the north through to the Fingal Valley in the south. These soils are generally gradational soils with gritty clay loam or sandy loam surfaces passing gradually into clay subsoils. They are low in pH and fertility, and are particularly prone to water erosion even on low to moderately sloping land. Waterlogging during the winter months is a problem in many areas because of low soil permeability. A significant limitation to the more extensive use of these soils for cropping is the fact that they occur within climatic zones that are not conducive to cropping, mainly because of the high risk of out-of-season frost. Therefore these soils are mainly used for grazing of sheep and cattle on improved pasture, although around the Scottsdale area some granite-based soils are used for the growing of vegetables.

Soils on basalt (krasnozems)

Red gradational soils on basalt (classified as krasnozems) occur mainly around the Scottsdale, Ringarooma, Branxholm and Winnaleah areas, although some small pockets occur around Pipers River and Pipers Brook. Krasnozems are among the most productive soils in Australia because of their excellent structure, drainage and moderate natural fertility. They have a strongly developed granular structure and are easy to work over a moderate range of moisture conditions. Organic matter content is initially high in the surface horizons. Almost all krasnozems on basalt within the region have been cleared and are used extensively for cropping and grazing (particularly dairy production). The main limitations to their use for cropping are steepness of slope, stone content and climate (frosts). In addition, they can overlay other rock types at shallow depth resulting in a mixture of soil types within the one paddock, causing difficulties with soil management. These soils are also prone to water erosion on steeply sloping land, requiring well-designed soil conservation systems and sound soil management practices.

Land degradation problems

The principal land degradation problems associated with soils within the region include water erosion, wind erosion, nutrient decline, structural decline, soil

acidification, waterlogging and salinity.

Although many of the soils are inherently highly erodible, some are only prone to erosion because of their position in the landscape. For example, the sandy soils and soils on the Mathinna Beds and granite are generally highly erodible because of their light surface texture and low organic matter levels. On the other hand, soils such as the krasnozems are generally of low erodibility, but because they often occur on moderate to steep slopes they are prone to sheet and rill erosion. The key management practice for all of these soils is the maintenance of surface cover and soil structure. Where paddocks are left bare, adequate soil conservation measures should be undertaken.

Salinity along the northern coastal areas of the region is a major problem having significant effects on agricultural productivity. The salinity is caused principally by the poor surface drainage patterns of the area resulting in high water tables.

Conclusion

Less than one-third of the total area of the region is used for agriculture. The majority of the soils are only capable of being used for grazing because of inherently low fertility, low permeability and/or high stone content. Other limitations to cropping include climate and slope. The best soils in the region are the krasnozems, which are used extensively for cropping.

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The Geology and Landforms of Northeast Tasmania

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Abstract

The Northeast is a geologically distinctive region of Tasmania. The Northeast is founded on marine turbidite rocks (the Mathinna Group) intruded by granitic rocks. This assemblage is distinctly different from the contemporaneous shallow marine shelf carbonates and clastics found west of the Tamar. It was formed at some distance from the 'Western Tasmania Terrane' and was transported to its present location by movements along the Tamar Mobile Belt. Much of northeast Tasmania has been relatively uplifted during long periods of its subsequent history, with only thin sequences of younger Permian sedimentary rocks being deposited in the present highland areas. The Permian rocks were intruded by extensive sheets of dolerite magma in mid-Jurassic times at the start of the breakup of Gondwana. Landform evolution during the Tertiary Period followed the development of increased landscape relief due to block faulting in Cretaceous to Early Tertiary times. Fluvial processes have shaped the landscape during most of its subsequent development, although basaltic lavas filled some valleys and altered drainage patterns during the Tertiary. An extensive area of the pre-Permian erosional surface has been exhumed and forms a prominent component of the present-day northeast Tasmanian highlands. The higher peaks, capped by resistant remnants of the dolerite sheets, underwent accelerated erosion during glacial climatic stages. The arid climatic conditions of the last glacial stage allowed the formation of extensive dune fields on the Bass Strait plains, a portion of which are preserved on the north coastal platform. The heights of relict shorelines of last interglacial age suggest that northeast Tasmania has undergone greater Quaternary uplift than most of mainland Australia. Land use patterns in northeast Tasmania have been strongly influenced by distinctive topographies and soils on particular bedrock and landform systems. Since geology and landforms also influence the distributions of biological communities, the conservation of biodiversity in the Northeast faces the problem that, whilst those communities which are least disturbed and least endangered have the best statutory protection, those most endangered are likely to be those characteristic of the more heavily disturbed bedrock and landform assemblages which have been favoured for settlement and agriculture.

Introduction

From the point of view of earth science, the area which is the subject of this symposium - bounded by the Tamar River valley axis to the west and the South Esk - Break O'Day River valley axis to the south - is distinct from the rest of Tasmania in its surface geology, and to some extent in its landforms, or geomorphology. This paper presents an overview of the complex geology and geomorphology of northeast Tasmania, and briefly points to the interrelationships between these, biogeography and land-use patterns.

Geology

The regional geology of the Northeast (fig. 1) is perhaps the best known of any region of comparable size in Tasmania. With the publication of the 'Alberton' geological map sheet in 1993 (McClenaghan et al. 1993) the Northeast became the first major region of Tasmania to have full geological mapping coverage at 1:50 000 and 1:63 360 scale. To a large extent, mapping was driven by the mineral potential of the region. The recent NETGOLD project conducted by Mineral Resources Tasmania has further upgraded and synthesised geological knowledge of the Northeast (McClenaghan & Calver 1994).
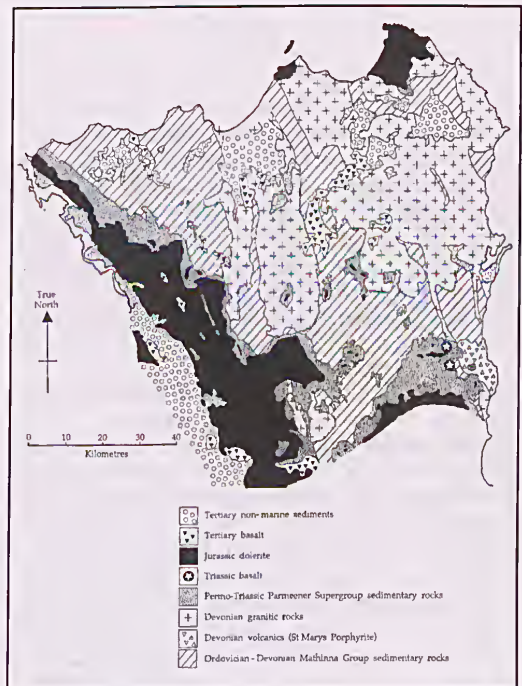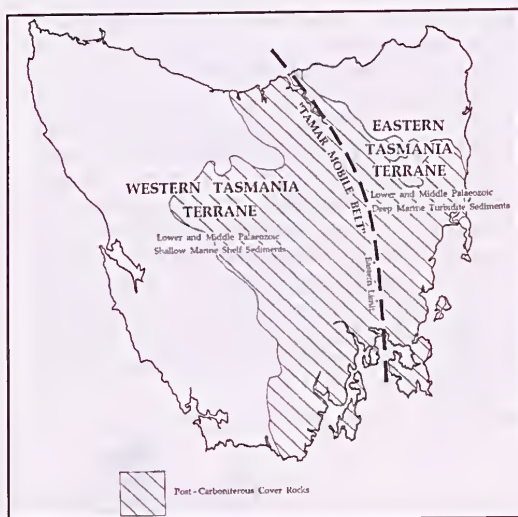

Fig. 1. Geological map of northeast Tasmania (adapted from McClenaghan & Calver 1994). Quaternary cover sediments have been omitted.

The Mathinna Group and the Eastern Tasmania Terrane

The oldest rocks in northeast Tasmania are widespread deposits of deep marine sediments of Ordovician to Devonian age (c. 480-400 million years old) known as the Mathinna Group (Powell et al. 1993). These consist of fine-grained clastic sediments, deposited under quiet deep marine conditions, alternating with beds of poorly sorted greywacke sandstones (turbidites) which were deposited by turbidity currents that occasionally poured down steep continental margin slopes (Baillie & Powell 1989). Fossils in the Mathinna Group are generally sparse, but include the extinct group of pelagic marine organisms known as graptolites.

Fig. 2. A greatly simplified geological map of Tasmania, showing the Eastern and Western Tasmania basement terranes separated by the Tamar Mobile Belt. The geologically distinctive character of northeast Tasmania results from the fact that it is the only large area in which the younger post-Carboniferous cover rocks have been stripped off the Eastern Tasmania Terrane to expose the basement Mathinna Group and granitic rocks at the surface.

While the Mathinna Group was being deposited in deep waters, the western two-thirds of Tasmania was a broad, shallow, continental margin shelf on which limestones and shallow-water clastic sediments were being deposited. The deep marine deposits of the Northeast are separated by only a few kilometres, across the Tamar River, from coeval shelf deposits near Beaconsfield. It is unlikely that such dissimilar rock associations could have been simultaneously deposited in such close proximity, and it is generally considered that the basement rocks of the Northeast were deposited in a more distant location and then tectonically transported to their present position by major earth movements (Baillie 1985). The Mathinna Group displays affinities with rocks in the Melbourne Trough of east Victoria (Powell & Baillie 1992).

The zone of tectonic disruption separating the Mathinna Group from the platform deposits of west Tasmania has been called the 'Tamar Fracture System' (Williams 1979) or the 'Tamar Mobile Belt' (Leaman & Richardson 1990, Leaman 1992), and divides Tasmania into two distinct geological units - the Western and Eastern Tasmania Terranes - along a zone between the Tamar Valley and Storm Bay (fig. 2). Although correlates of the Mathinna Group underlie much of east Tasmania, it is only in the Northeast that younger cover rocks have been eroded off to expose extensive areas of the basement rocks.

The Tabberabberan Orogeny, granitic intrusions and mineralisation

The deposition of the Mathinna Group was halted by the onset of the Tabberabberan Orogeny, a period of folding, uplift and mountain-building in east Australia in mid-Devonian times. Intense folding of the Mathinna Group was followed by the intrusion of huge volumes of granitic magmas in a series of pulses between 356 and 392 million years ago (Cocker 1982, McClenaghan 1989). Although most of the currently exposed granitic rocks cooled and solidified below the surface, the magmas reached the Devonian surface near St Marys to form an accumulation of volcanic rocks known as the St Marys Porphyrite (Turner et al. 1986). This magmatism was in turn followed by a multi-scale 'kinking' and 'mega-kinking' fold event at some time prior to the deposition of the Parmeener Supergroup (Goscombe et al. 1994). Low-grade metamorphism resulting from tectonic stresses has transformed the finer-grade Mathinna Group sediments to shales and slates, which have been mined at Bangor and Back Creek in the East Tamar area.

The areas of exposed granitic rocks in the Northeast, known as the Blue Tier, Scottsdale and Eddystone Batholiths, are the largest areas of exposed granitic rocks in Tasmania, and are roof projections of a much larger composite batholith which underlies east Tasmania from Flinders Island to Tasman Peninsula (Leaman et al. 1980). Granitic magmas also altered the parts of the Mathinna Group through which they rose, producing aureoles of hardened siliceous rock known as hornfels. These aureoles have had a major influence on landform development. Following geologically recent uplift and erosion, they have formed prominent ridges standing above the more erodible granites and unaltered Mathinna Group rocks to either side. Prominent examples of these granite-margin hornfels ridges include the Sideling Range and circular ridges at Lisle.

Much of the metallic mineralisation in northeast Tasmania is associated with the Devonian granitic rocks, and includes deposits of tin, tungsten, copper and lead-zinc-silver within, above or surrounding granitic intrusions at places such as Rossarden, Blue Tier and Scamander (Collins et al. 1989). Gold deposits occur in major linear fracture zones in the Mathinna Group which roughly parallel the Tamar Mobile Belt (Bottrill et al. 1992, Taheri & Findlay 1992). Taheri and Findlay (1992)

consider the gold deposits, although spatially related to Devonian granodiorites, may have originated through metamorphic processes unrelated to and possibly post-dating the granitic intrusions. Large alluvial deposits of tin and gold derived from the Devonian hard-rock mineralisation accumulated in Tertiary fluvial sediments in the South Mt Cameron area and the Lisle-Denison goldfields.

The tectonic transport of northeast Tasmania along the Tamar Mobile Belt to its present position probably took place during the Tabberabberan Orogeny, possibly prior to the granitic intrusions (Bottrill et al. 1992). Although this transport has long been thought to have been a lateral megashear (Williams 1989), Leaman (1994) and Leaman et al. (1994) have argued that transport from the northeast occurred by low-angle thrusting of slices of the basement rocks.

The Late Carboniferous landscape of northeast Tasmania

The uplift of Tasmania during the Tabberabberan Orogeny was followed by a long period of sub-aerial exposure during the Carboniferous Period (which ended c. 300 million years ago), when Tasmania, including the Northeast, underwent prolonged erosion. Large areas of Tasmania were reduced to plains during this time. With the onset of renewed sedimentation in Late Carboniferous and Early Permian times, this ancient land surface was buried beneath younger rocks (see below); these in turn have been partly stripped off by uplift and erosion to re-expose the pre-Permian landscape surface. Although fragments of this surface have been re-exposed in many parts of Tasmania, the largest portion of the exhumed surface is found in the northeast Tasmanian highlands. Here it forms an extensive gently sloping plateau, with residual patches of younger overlying rocks forming peaks which rise above the general level (Davies 1965, Caine 1983). To the south, the surface forms a broad valley deepening towards Fingal and then plunging beneath Fingal Tier as a buried unconformity (Calver 1987). The surface exhibits relatively steep slopes in some parts of the Northeast (Martini & Banks 1989, Sharples 1994).

The Parmeener Supergroup

The onset of renewed sedimentation in Tasmania was heralded by a period of glaciation which began in Late Carboniferous times and waxed and waned for over 50 million years through the Permian Period. Glacial erosion and the deposition of tillites occurred in west and central Tasmania, but glaciers appear to have been absent from most of the Northeast, which was peripheral to the main areas of glacial ice (Hand 1993). Instead, much of east Tasmania probably underwent 'mass wasting' erosion (Clarke 1989) as a result of periglacial freeze-thaw processes. Intricate networks of sedimentary ('neptunian') dykes at the unconformity (landscape surface) may represent infilling of surface cracks opened by ice wedging. An outstanding example of these features

occurs near Rossarden (Williams 1967).

Following the deposition of tillites in Tasmania, a long cycle of marine and terrestrial sedimentation took place during Permian and Triassic times (c. 300-200 million years ago) resulting in the accumulation of the mudstones, siltstones, sandstones and minor limestones, coals and conglomerates of the Parmeener Supergroup (Banks 1973). The main marine depositional basin was located west and south of the Northeast, subsiding along the axis of the Tamar Mobile Belt. Throughout most of this time the Northeast remained a generally upstanding area, with the result that sedimentation commenced late (during Early Permian times), and the Parmeener Supergroup as a whole is much attenuated in northeast Tasmania.

Near Mt Victoria, the basal Permian sediments are massive quartz sandstones and conglomerates deposited under terrestrial fluvial conditions (Everard et al. 1992, McClenaghan et al. 1993). These are today exposed in impressive cliffs with large overhangs and caves which are important archaeological sites (Ross 1990) and also display unusual ferruginous stalactites (Sharples 1994). The thin sequence of younger overlying Permian rocks includes marine siltstones and thin limestones, the latter being more prominent near St Marys at the southern margin of the Northeast.

Renewed uplift of the Northeast at the end of the Permian Period resulted in the cessation of Parmeener Supergroup sedimentation in the highlands, and a depositional hiatus in the St Marys area which lasted until mid-Triassic times (Forsyth 1989), although thick Early Triassic fluvial quartz sandstones were deposited at Blessington and elsewhere in Tasmania at this time. Terrestrial sandstones with some coals began to be deposited near St Marys during the mid-Triassic, and volcanic activity resulted in the extrusion of basaltic lavas in the same area (Turner & Calver 1987). Deposition of clay-rich lithic sandstones with some major coal seams continued at Fingal and St Marys into Late Triassic times, although the highlands to the north remained uplifted and experienced little or no deposition (Bacon 1991).

Dolerites and the breakup of Gondwana

The timing of the end of deposition of the Parmeener Supergroup is uncertain; deposition may have continued into the Jurassic Period in some parts of Tasmania. At the latest, deposition was terminated by uplifts and tectonic movements associated with the intrusion of widespread dolerite magmas in mid-Jurassic times. Large sheets of dolerite magma intruded into the sub-surface rocks ca. 175 million years ago in parts of what are now Tasmania, Antarctica, South Africa and South America. Their intrusion appears to have been related to a period of crustal extension at the beginning of the break-up of the supercontinent of Gondwana (Morrison et al. 1989).

In northeast Tasmania, it is thought that the dolerite-

capped peaks of the highlands represent the remnants of an originally continuous sheet which once extended across much of that area (Everard et al. 1992). Multiple dolerite intrusions may be present elsewhere in the Northeast. Block faulting associated with the dolerite intrusions rejuvenated the Tasmanian landscape, after which erosion over the next 75 million years or so reduced much of it to a plain once again.

The separation of Tasmania from Antarctica and New Zealand began around 100 million years ago (Veevers et al. 1991). The accompanying crustal extension caused another period of block faulting in and around Tasmania during Cretaceous to Early Tertiary times, between 100-65 million years ago (Morrison et al. 1989). The Tamar Graben on the western margin of the Northeast formed as a major structural trough considered by Leaman (1992) to be the result of extensional pull-back on the underlying basement thrust faults of the Tamar Mobile Belt. Mounts Arthur and Barrow and Ben Lomond were left as upstanding horst blocks peripheral to the graben.

Cretaceous igneous rocks

Igneous rocks of demonstrated Cretaceous age are only known in Tasmania from Cygnet and from the Cape Portland area of the Northeast (Ford 1989). The Cape Portland Complex comprises an appinitic suite of andesite, lamprophyre and porphyrite flows, dykes and irregular intrusions (Jennings & Sutherland 1969). Radiometric dates of 101.3-102.3 ± 2.6 my BP were obtained by McDougall and Green (1982). Basalts and a lamprophyre yielding a similar age of 98.7 ± 0.8 my BP have been drilled within Permian rocks at Musselroe Bay (Baillie 1984).

Tertiary landscape development, fluvial systems and vulcanism

Cretaceous - Tertiary block faulting resulted in dramatically increased relief in the Tasmanian landscape generally, and is probably the event from which much of the present cycle of landscape development and erosion in the Northeast can be traced, albeit some aspects of the present landscape may date back to the Jurassic faulting (Colhoun 1989). The major river systems of the Northeast probably developed in Early to Mid-Tertiary times, and fluvial and lacustrine sediments were deposited over large areas, particularly in the Scottsdale Basin (north of Scottsdale), the Ringarooma and Boobyalla River valleys, the South Mt Cameron Basin, and the lower George River. Hill and Macphail (1983) have dated Oligocene (mid-Tertiary age) organic sediments at Pioneer which were deposited before a local extrusion of lavas. Basaltic vulcanism occurred episodically in the Northeast during much of the Tertiary, although it is thought to have peaked in mid-Tertiary times (Sutherland 1989, Colhoun 1989). The vulcanism filled valleys and buried large areas of fluvial sediments beneath floods of basaltic lavas and ashfall deposits, especially in places such as the

Scottsdale Basin and the Weld and Ringarooma River valleys. Tertiary river channels were diverted to new courses, establishing a modified drainage pattern which was the precursor to the present one (Nye 1924, Colhoun 1989). Subsequent to the vulcanism, continued erosion removed large areas of basalt cover, re-exposing the older fluvial sediments. Tough ferricrete duricrust layers now cap some low mesa-like residual hills of fluvial sediments in the north Scottsdale Basin - Boobyalla River areas, and are thought to have formed due to iron enrichment and cementation of the fluvial sediments during removal of the overlying basalts (Brown & Moore 1982).

Geomorphology

In contrast to the bedrock geology, there has been little study of landform development in the Northeast. The only major systematic studies have been those of Caine (1983) on glacial and periglacial processes on mountaintops, and of Bowden (1983) on aeolian landforms on the north coastal platform. This contrast in emphasis can be attributed to the fact that whereas the study of bedrock geology is of direct economic utility, the major applications of geomorphic knowledge - which deals with processes affecting the earth's surface - lie in environmental management, which has only in very recent times been widely recognised as an important goal of land use planning.

Much of the present landscape of the Northeast is a 'fossil' one. Many of the landforms we see today were largely produced by processes which occurred in the past, and are being only slowly modified by present-day fluvial processes. The geomorphic development of the Northeast has in many respects proceeded in an episodic fashion; long periods of relatively slow development have been punctuated by periods of rapid landform change, related in particular to block faulting in Early Tertiary times, episodes of vulcanism during the Tertiary, and to the high-energy processes of the Cainozoic glacial climatic stages. Each of these phases of dramatic and geologically rapid environmental change has undoubtedly had its effect on the biogeography of the Northeast.

Fluvial processes

Fluvial processes - the effects of liquid water in the terrestrial environment - are today the major geomorphic processes active in the Northeast, and probably have been for most of Cainozoic times. However, although some hydrological studies have been undertaken in the Northeast, fluvial landforms have been very little studied, most current knowledge being based on observations synthesised by Davies (1965), with little systematic investigation since.

As noted above, the present-day drainage systems of the Northeast probably largely date from a dramatic increase in the relief of the Tasmanian landscape resulting from Cretaceous to Early Tertiary block faulting, and were

subsequently modified by Tertiary vulcanism. Subsequent influences on the river systems include periods of increased slope instability and higher peak waterflows during cold glacial climatic phases during the Cainozoic, and minor tectonic uplift and tilting which may be continuing to the present day.

Drainage channels on dolerite and Parmeener Supergroup bedrock in and adjacent to the Tamar Graben show strong linear and rectilinear patterns resulting from erosion along faults and joints, in a fashion which is characteristic of Tasmania's Fault Structure Province (Davies 1965). However, the intense folding of the older Mathinna Group rocks has in most places exerted little control on drainage patterns, due to the lack of the marked lithological contrasts which have allowed trellised drainage patterns to form on the more heterogenous Fold Structure Province rocks of west Tasmania.

Much of the granitic bedrock of the Northeast is intensely fractured and has formed a deeply weathered, dendritically dissected landscape. However, some granitic masses, most notably alkali-feldspar granite bodies including Mt Cameron and Mt Stronach, have widely spaced joint fractures and have eroded into bold domed residual mountains displaying angulate joint-controlled drainage. At some exposed ridgetop sites such as at Cube Rock on Mt Cameron (fig. 3), solutional weathering features generally considered characteristic of more soluble limestones have formed on the granitic rocks, including flutes and solution pans or 'gnammas' (Twidale 1971).

As is the case over much of Tasmania, many watercourses in the Northeast are underfit streams occupying valleys too large for the present stream to have carved out, and

Fig. 3. A cluster of gnammas (solution pans), some with interconnecting runnels, near Cube Rock on Mt Cameron. These landforms are produced by predominantly solutional weathering processes. Although the geomorphic effects of solutional processes are best recognised in karst systems formed on carbonate bedrock, under appropriate conditions they may form on less soluble silicate rocks such as the granites illustrated here.

contain coarse cobbles and boulders of a calibre beyond the capacity of the present stream to transport except under exceptional flood conditions. These characteristics of Tasmanian streams are thought to have resulted in part from the carving out of the channels by higher waterflows during more humid and less seasonal phases of the Early Tertiary (Hill 1990, Augustinus & Hannan 1991). Then, during the Pleistocene, lack of vegetation on slopes in arid cold periods facilitated periglacial erosion and valley widening, so that large volumes of coarse sediment entered the streams from the unstable slopes (Davies 1965, Goede 1965). Large river valleys, including those of the upper South Esk and St Patricks Rivers, display well-developed alluvial terraces which are considered to have formed from the deposition of copious quantities of coarse sediment transported by the energetic peak flows of Pleistocene rivers during seasonal thaws (Davies 1965).

Davies (1959) identified fragments of broad erosional plains in the Northeast which he considered as evidence of erosion to successive statewide base levels at various stages of intermittent tectonic uplift during the Cainozoic. Of these, the most recent Lower Coastal Surface - represented by the north coastal plain - truncates geological structures and is undoubtedly the result of erosion to a regional base level. However, some of the other surfaces correspond to local structural surfaces, notably the top of the dolerite sheet and the exhumed pre-Permian erosion surface, and may simply represent erosion to local, structurally controlled base levels rather than to statewide base levels as maintained by Davies. In one pertinent case, the exhumed pre-Permian surface declines gradually from the level of Davies' Lower Plateau and St Clair Surfaces in the northeast Tasmanian highlands to the level of his Higher Coastal Surface northeast of Fingal, without the intervening escarpments which should exist if these were distinct, successively developed surfaces eroded to regional base levels rather than a single structurally controlled surface (Sharples 1994). The issue of statewide base level erosion surfaces in Tasmania has been little studied since Davies' work, and more research is needed to clarify the significance of erosion surfaces in the Northeast.

There is evidence (see below) that Tasmania has undergone - and is possibly still undergoing - uplift and tilting in the far Northeast during Quaternary times. Whilst the effects of such tilting on the development of fluvial systems in the Northeast awaits unravelling, it is interesting to speculate on whether tilting could explain the anomalous course of the Break O'Day River, which has its headwaters only 7 km from the east coast, and yet flows westwards away from the coast to join the South Esk River and drain into the Tamar Graben.

Karst

Karst landforms, which result from a geomorphic process involving the dominance of chemical solution weathering and precipitation that is best expressed in carbonate rock types, are poorly developed in the Northeast, as indeed is the case for all of east Tasmania. Limestones in east and northeast Tasmania are restricted to thin and generally impure horizons within the Permian rocks, in contrast to the thick Precambrian dolomites and Ordovician limestones of west Tasmania, and the lower precipitation in the eastern half of the State compared to the west further reduces the potential for karst development.

Whilst some minor karst landforms are known at places such as the northern side of Mt Durham, the only substantial development of a karst landform system in the Northeast occurs in Permian limestones at Mt Elephant, southeast of St Marys, where the limestones are relatively pure and experience a higher average annual rainfall than any other limestone area in east or northeast Tasmania (Sharples 1994, Kiernan 1995). Known karst features at Mt Elephant include dolines, swallets, numerous springs, shafts up to 17 m deep, cave passages up to 35 m long, speleothem displays, and exposed surface fluting (rundkarren) of a type whose subsoil origins attest to accelerated soil erosion (Kiernan 1995). Local folklore refers to other lost caves in the area, including a legendary 'Mile Long Cave' whose entrance was reputedly blocked by a farmer around the turn of the century (Eberhard & Eberhard 1989). This karst system is important as the best development of terrestrial karst in east Tasmania, and in Permian limestones anywhere in Tasmania.

Landform processes in northeast Tasmania during the Cainozoic Glacial Climatic Phases - glaciation, periglaciation and aeolian activity

Tasmania has been subject to at least six glacial climatic phases during Cainozoic times (Kiernan 1989), with the earliest possibly as long ago as 36 million years, and the most recent ending about 10 000 years ago (Macphail & Peterson 1975, Macphail et al. 1993). Climatic gradients across Tasmania made the eastern half of the State a marginal glacial environment (Davies 1962), and glacial ice is only known to have been present on Ben Lomond during two glacial climatic phases (Caine 1983). Caine has identified an earlier Plateau Glaciation phase, during the maximum extent of which nearly the entire Ben Lomond plateau was covered by two ice caps. The more recent Cirque Glaciation, considered to have been the Last Glaciation, produced only three small cirque glaciers on the lee side of the plateau. However, increasing data on glaciation elsewhere in Tasmania which has accumulated through the 1980s raises the possibility that glacial ice could have affected Ben Lomond, and possibly some other northeast Tasmanian peaks, during more than the two phases identified there to date.

However, the effects of the glacial phases were not restricted to glaciers; climates were generally colder and more arid throughout Tasmania, which allowed periglacial (freeze-thaw) and aeolian (wind erosion and deposition) processes to rapidly modify the landscape over much of the Northeast. Also associated with the glacial and periglacial processes were high-energy meltwater streams which caused accelerated development of fluvial systems, as described above.

The effects of periglacial processes are most marked on the dolerite peaks of the Northeast, where the close fracturing of the dolerite (commonly much less than 0.5 m fracture spacings) predisposed it to ice shattering, but the tough crystalline nature of the shattered rocks allowed them to survive slope transport over long distances. Caine (1983) analysed periglacial processes in the Northeast in terms of a 'Debris Cascade' which began at high altitude with erosion by frost shattering and ice wedging. Spectacular high-altitude landforms such as columnar cliffs, tors, and leaning columns were left behind by such erosion, while the eroded rock fragments - often of large boulder size - were transported downslope by gravitational falling and sliding, by solifluction freeze-thaw processes, and by humid slumping. At the highest altitudes, periglacial processes transported boulder-grade blocks over low-angle plateau surfaces producing blockstreams or 'allochthonous blockfields'. The blockfields of Mt Barrow (fig. 4) and the Ben Lomond plateau are amongst the most extensive such features in the world (Caine 1983), and in the case of Ben Lomond have formed subsequent to the Plateau Glaciation. Talus also accumulated at the base of cliffs and was then, along with blockstream-derived material, moved long distances down the steeper mountain slopes by solifluction creep processes. The result today is that the slopes of many northeastern Tasmanian peaks are mantled by dolerite colluvium which commonly overlies sedimentary or granitic bedrock around the base of the dolerite mountains. Such slope deposits occasionally slumped, particularly during thaws or more humid periods of the glacial climatic phases, producing hummocky slope profiles which in places such as the lower southeastern slopes of Mt Arthur include large depressions with permanent ponds (Sharples 1994). Such ponds are relatively common in east Tasmania, and their sediments have the potential to provide pollen records extending throughout the Holocene at many scattered sites. Ponds are rarely shown on topographic maps, however, due to their generally small size. Doleritic colluvium on steeper slopes is prone to renewed instability under modern conditions after very heavy rain, particularly if sufficiently disturbed by poor land management.

Slope deposits of probable periglacial origin are also derived from the Mathinna Group rocks at places such as The Sideling, Lisle and near Mt Paris. Coarse, crudely stratified slope deposits in the upper South Esk and St Patricks River valleys are in some cases probably alluvial fan deposits. Stratified colluvial deposits of finer grade

have been considered to be Pleistocene snow-melt slopewash deposits known as grèzes litées (Colhoun 1989). However, Holocene dates have been obtained from some of these deposits (fig. 5; Caine 1978), suggesting that at least some of them represent post-glacial phases of Holocene slope instability (Thomas 1991).

While mass-wasting and slope transport mechanisms strongly affected the highland areas, large low-lying plains existed in the Bass Strait area as a result of significantly lowered sea levels during the glacial phases. In the Last Glacial Phase, much of Bass Strait and the present north coastal platform was a broad, arid, windy and sparsely vegetated plain (Bowden 1983). Marine sands deposited during the previous Interglacial Stage were remobilised to form extensive longitudinal dunes, some many kilometres long. Deflation hollows with associated lunettes also formed. The dunes preserved above sea level on the coastal platform, now vegetated and relatively stable if undisturbed, constitute the largest portion of a Pleistocene inland dune field preserved in Tasmania. A large complex of transverse and parabolic dunes of Holocene coastal origin is active along the present coastal fringe, particularly on the eastern sides of Anderson and Ringarooma Bays.

Fig. 4. An allochthonous blockstream on Mt Barrow. Periglacial (freeze-thaw) processes had a dramatic influence on landform development in northeast Tasmania during the Pleistocene glacial climatic stages, resulting in rapid erosion (or 'mass wasting') at high altitudes, and the transport of large volumes of rock downslope, sometimes over very low gradient slopes. In the blockstream illustrated here, large dolerite boulders were slowly transported over considerable distances by the effects of repeated freezing and thawing of ground ice. The blockstreams on Mt Barrow and Ben Lomond are amongst the largest of their type in the world.

Marine and coastal landforms

During the Last Interglacial Stage, a global eustatic sea level rise to about 6 m above present sea level has been inferred (Chappell & Shackleton 1986). However, Last

Fig. 5. Stratified slope deposits beside the Mathinna Plains Road, above Dans Rivulet. Although the deposit is now vegetated and stable, a Holocene radiocarbon date obtained from buried charcoal (Caine 1978) is indicative of post-glacial slope instability in northeast Tasmania. The patterns, timing and causes of Holocene slope instability in Tasmania remain poorly understood, but may be related to climatic variations or human disturbance, or both, and thus are likely to provide information vital to understanding the biogeographical development of the Northeast.

Interglacial shorelines around most of mainland Australia are generally below 4 m ASL (Murray-Wallace & Belperio 1991). In marked contrast, Last Interglacial sea levels in Tasmania have been identified at around 20 to 24 m above present sea level at sites including Mary Ann Bay in south Tasmania (Murray-Wallace et al. 1990), while a shoreline scarp of probable Last Interglacial age occurs at 32.5 m ASL at Stumpys Bay in the Northeast, in association with fossiliferous marine sediments (Bowden & Colhoun 1984, Baillie et al. 1985, Murray-Wallace & Goede 1991). These elevated shorelines indicate geologically recent tectonic uplift of Tasmania with respect to mainland Australia, with an implication that a higher rate of uplift has occurred in northeast Tasmania.

Bowden and Colhoun (1984) and Murray-Wallace and Goede (1991) consider that neotectonic uplift of Tasmania may be attributable to crustal doming over a mantle hotspot, or to crustal adjustments associated with the northwards movement of the Australian Continental Plate. The possibility that uplift is ongoing in northeast Tasmania is supported by the fact that the most intense period of Tasmanian seismic activity documented in historical times occurred during the period 1883 to 1885, with the epicentres being located just off northeast Tasmania (Richardson 1989); however Murray-Wallace and Goede (1991) found no evidence to support ongoing Holocene uplift.

The age of onset of neotectonic uplift in mainland Tasmania is unknown. If it has been occurring over a period encompassing several glacial and interglacial stages, it is possible that fossil shorelines from

Pleistocene pre-Last Interglacial stages may have been uplifted higher than the Last Interglacial shorelines. In this respect, marked changes of slope (shorelines?) and gravel deposits (wave-washed beach gravels?) between 110 and 50 m ASL in the St Helens to Piccaninny Point area may be worthy of further examination, although a Tertiary origin for some of these sediments is also possible (Twelvetrees 1911, Walker 1957, Turner & Calver 1987, McClenaghan et al. 1992). Bowden & Colhoun (1984) have suggested that marine deposits at 49 m ASL and 71 m ASL at Rockbank in northeast Tasmania may belong to Pleistocene interglacial stages preceding the Last Interglacial.

Concluding remarks: implications of geology and geomorphology for land use and biogeography

Geology, landforms and soils play a fundamental role in determining the accessibility, capability and suitability of land for particular human uses. In northeast Tasmania, the characters and distribution of areas primarily used for mining, agriculture, forestry and conservation reserves exhibit strong correlations with geology and landforms (Sharples 1994).

Geology and landforms also partly determine the sorts of biological communities which will be found in particular areas. It can be assumed that the distinctive areas which have been most favoured for intensive human settlement and industry - particularly farming and alluvial mining - will by virtue of their physical characteristics have been favoured by particular biological communities. However, biological communities in areas favoured for human settlement will probably have been most disturbed by human activities, and remnants may therefore be in need of careful conservation management. In contrast, biological communities which are characteristic of areas less intensively used for human activities - especially areas which are now State Reserves and to some extent areas of State forest - are likely to be relatively undisturbed and less at risk.

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Some Man-Induced Geomorphic Changes in the
Coastal Environment of Northeast Tasmania
Since European Settlement and Some Related Observations on Coastal Vegetation

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Abstract

The origin of the coastal dunes of northeast Tasmania is related to sea level fluctuations and consequent erosion patterns and sediment movements during and since the Pleistocene Ice Age. At the time of European settlement, high and steep frontal dunes existed close to the coast, but a century of burning and grazing resulted in the destruction of protective vegetation and triggered extensive wind erosion and the general eastward drift of massive sand blows. Until about 1950 most of the coast country affected by the dunes comprised bush runs of low value, so little effort was made to halt the encroaching sand. However, developments in agricultural techniques following World War II made it possible to transform much of this country into highly productive farms. The Waterhouse Soldier Settlement, northeast of Bridport, was one such area where it was found necessary to undertake a large-scale dune stabilisation program to protect the new farms. Over the last forty years most of the large sand blows at Waterhouse have been stabilised and over that same period public attitudes to land use and management have also evolved greatly. The high conservation value of the complex of coastal dunes and wetlands of the Northeast has now been recognised, with consequent changes in dune stabilisation practices and objectives. The scale and impact of dune movements is illustrated with case histories and some observations are made on pioneer dune vegetation and on interrelationships between dune geomorphology and ecology. In conclusion, reference is made to the impact of alluvial tin mining on the Northeast, and especially to estuarine environments, and the hope is expressed that the spirit of Landcare will last beyond the Decade of Landcare and will have a substantial influence on future land management practices in Tasmania.

Introduction

This paper is not intended to be a highly scientific treatise on coastal geomorphology. It is more in the nature of an anecdotal record of some personal observations and experiences extending over more than forty years of involvement with the dune lands of northeast Tasmania. I lived and worked for nearly twenty years in the region. For most of that time I was in charge of the Lands Department's dune stabilisation program at Waterhouse and other problem areas around Tasmania. During that time I had many opportunities to observe natural processes at work - and often to interfere with those processes! Later, while Chief Land Management Officer in the Lands Department, and since then whilst working as an environmental consultant, I was able to continue both my involvement with the management and conservation of dunes and wetlands around the State and my observation of natural processes at work over the years.

A very valuable experience for me was my contract with the Plomley Foundation to undertake a study of the wetlands of northeast Tasmania. This work further impressed upon me the very close interrelationships between the ecology and geomorphology of the dunes and wetlands. It also further increased my awareness of the impacts on these dynamic and fragile systems of human activities, of other animals, both native and exotic, and of chance happenings such as storm events, droughts and fires, all of which together have created the fascinating diversity of plant communities and land forms

that are so characteristic of the coastlands of northeast Tasmania today.

Origin of the Holocene dunes

Tasmania sits near the southeast corner of the continental shelf of Australia and the floor of Bass Strait was exposed to various degrees on several occasions during peaks of glaciation through the Pleistocene Ice Age. At these times the climate was predominantly arid and very windy, although it was interspersed by periods of heavy rain so that the Bass Strait land bridge suffered erosion by both wind and water. At other times, corresponding to interglacial phases, sea level rose to cover the land bridge. With the waning of the last glacial stage, sea level rose steadily towards its present level and wave action swept large volumes of sand across the submerged sea bed and onto the shores of northeast Tasmania and the Bass Strait islands.

The last ten thousand years - the Holocene era - has been a time of very limited change of sea level, but during this time wave action has continued to move sand from the sea bed to the shore, from where the prevailing westerly winds have moved it up into immense dunes which can be seen in a modified form today. It is believed that around Tasmania and much of southeast Australia, most of the seabed reserve of sand accessible to swell waves at the present sea level has been delivered to beaches, and that in general our sandy shores are now in a rather unsteady state of equilibrium with the sea or are retreating before the elements.

Condition at the time of European settlement

Through the Holocene era big frontal dunes built up, some 30 m or more in height, which then became unstable and from time to time broke away to drift eastwards as parabolic dunes, some travelling 3 km or more before becoming stabilised again. It is likely that at the time of European settlement most of the coastal dunes were fairly well vegetated although many of the frontal dunes were high, over-steep and not very stable. Many frontal dunes would have been covered with coast wattle (*Acacia sophorae*). Elsewhere dunes would have supported a variety of mixed shrubberies or stunted woodlands dominated by banksias, she-oaks or eucalypts, with heath, sedgelands or other wetland communities between and behind. There were some active sand blows which may have been triggered by Aborigines' fires, but in general the dunes were probably in a quasi-stable condition. Before European settlement, 'triggering events' may have been severe storms or fires following periods of drought. Some fires were started by Aborigines, others may have been started by lightning.

Firestick farming

The early settlers developed farms on the best and most fertile land they could find. They ploughed, fertilised the soil, sowed pastures and grew crops, but they used the less fertile coastlands, including the dunes only as rough grazing runs which they managed by bush burning. 'Firestick farming' and over-stocking with sheep and cattle remained common practice as late as the 1960s. This hard treatment resulted in the rapid degradation of the dunes and the triggering of sand blows in many parts of the State. By the 1880s marram grass (*Ammophila arenaria*) had been introduced to Tasmania from Britain as a dune-fixing grass which could tolerate grazing and burning and still thrive. It was probably first introduced by the Van Diemens Land Company which planted it extensively on its properties on the Northwest Coast.

Although marram grass was well-established on some properties and beaches in the Northeast in the 1920s and probably much earlier, there were land owners who saw no merit in paying to plant marram grass except, perhaps, to protect a house or a particularly good piece of land. In the early 1960s a leading farmer suggested that trying to halt the dunes was perhaps even counter-productive. He said that as it moved eastwards, the sand was only burying useless bush, and the ground exposed from under the sand on the west soon grew up with sedges, coast wattle and volunteer pasture species which provided quite a lot of good feed. At all events, by the 1950s there were many thousands of hectares of bare sand drifting eastwards across the coastal plains of northeast Tasmania towards what was to become some of the State's best livestock-producing country.

New pastures, new attitudes and new problems

By the late 1940s agricultural scientists around Australia had made important discoveries relevant to the development and management of coast country. By the appropriate application of superphosphate, lime and trace elements, the use of improved pasture species and the inoculation of clover seed and the use of new drugs to control parasites in livestock, the stock-carrying capacity of coast country was lifted tenfold. Stock could now be kept permanently healthy on the coast where previously they would decline and die if kept there for more than six or eight months at a time.

In the post-war boom years these technical breakthroughs were quickly followed by large-scale development projects on coast country from Western Australia to southern Queensland. In northeast Tasmania through the 1950s and 1960s the State and Federal governments jointly developed the Waterhouse Estate for soldier settlement while Ernest and Maurice Mills from Cressy developed large tracts west of Bridport and at Cape Portland. Years later their example was followed by others. Between 1950 and 1980 many thousands of hectares of coastal heath, scrub and wetlands were cleared, drained and sown to pasture. The new value of coast country called for a marked change of attitude in the management of the sand dunes now drifting on a massive scale.

Unfortunately, in developing the Waterhouse Settlement, land clearing was extended in various places far too close to active sand blows before the authorities realised the danger. The year 1956 was a very windy season and to the dismay of the authorities sand began to stream across new pastures, burying fences and blocking drains. One sand blow advanced almost half a kilometre across new pastures in about four months. In that year the State Government established the Sand Dune Reclamation Unit at Bridport to initiate the stabilisation of the dunes and to protect the Soldier Settlement Scheme at Waterhouse. Now, almost forty years later, and with only one of the original soldier settlers still living on his block, the Waterhouse sand dune reclamation project is near the end of the primary marram planting stage. Even so, it will be years before the whole dune area can be considered safely stabilised.

During those forty years there has also been an evolution of attitudes towards the dunes and wetlands. Conservation values have been given higher priority though the protection of the Waterhouse settlement is still the prime concern in the management of the Waterhouse Protected Area. This shift in attitude has been reflected to some extent in the planning and implementation of works. Wetland habitats are protected where possible and instead of being levelled for planting, dunes may be encouraged to develop steeper profiles to give variety of habitat and scenery. Efforts are sometimes made to use native species rather than marram grass, and bush regeneration is

encouraged rather than the planting of pines.

It is appropriate to record here that David Paton, a research agronomist in the Tasmanian Department of Agriculture, played an important part in the practical application of research to the development of pastures on coastal heathlands in northeast Tasmania. But support from Paton also carried much weight in the Government's decision that the Waterhouse Point area north of the old Waterhouse homestead property should not be developed as pasture for soldier settlement but should be added to the Waterhouse Reserve (later Protected Area) and kept as an undeveloped heathland reference area.

Meanwhile, a different sort of problem affected the fishing town of Bridport. There are big dunes on East Sandy Point, some 10 km to the northwest. Thirty-five years ago several sand blows were moving across the scrub-covered headland. One had just reached the eastern shore and was beginning to spill sand into Anderson Bay. The other sand blows had not advanced so far. Fifteen years later three large sand blows were pouring huge volumes of sand into the bay and the wave-induced longshore current was transporting it around the coast towards Bridport. Over the next few years the beaches at Bridport were regenerated wonderfully, but the fishing fleet was having trouble navigating the bar and the channel to reach the wharf. The estuary was being filled with sand.

Eventually the Government was prevailed upon to take action. The channel has been dredged, rock training walls have been built and the dunes on East Sandy Point have been halted. The sea has eroded the end of the dunes back to uncover rocks which had been hidden for years, while the back end of a large slug of sand is working its way around the coast and will continue to feed sand to Bridport for years to come.

Much of the sand from East Sandy Point has bypassed Bridport and, accumulating in the corner of the bay about 3 km further east, is now diverting and partly blocking the mouth of Adams Cut, the relocated outlet of the Great Forester River which formerly debouched at Bridport. The Cut was excavated in 1926 to make possible the drainage of extensive tea-tree swamps which were subsequently developed into highly productive farmland. Since then, land clearing, drainage and development, and the extraction of water for irrigation, domestic and industrial use in the upper catchment of the Forester River has greatly altered the flow of the river in its lower reaches. In particular, its power to keep the mouth of The Cut open in summer is much reduced, and this, together with the accumulation of sand in the corner of the bay, will probably necessitate the construction of training walls to maintain the river outlet.

It is also interesting to note that the stabilising of the dunes on East Sandy Point to protect the port of Bridport met with considerable community opposition on the grounds that it was useless and unjustified interference with an area of natural beauty, high recreation value and great interest for the study of natural processes at work. The Northeast certainly provides some persuasive examples of the need for environmental impact assessment prior to initiating new developments or works and for giving adequate weight to geomorphological studies in such assessments!

General observations on geomorphic changes

I consider myself fortunate that throughout my working life I have had jobs that have enabled me to observe coastal changes around Tasmania, and especially along the Northeast coast over the past forty years. It has been fascinating, and the coast is always beautiful. Often I played at being God and altered the course of nature, but at other times I sat back and watched things happening. The scale and rate of such 'happenings' often surprised me.

In the 1950s northeast Tasmania was near the end of a 100-year regime of frequent burning and over-grazing and also experienced some very windy seasons. The dunelands from the Tamar to Musselroe Point were in a sadly degraded state and were changing rapidly. Most of the remaining big frontal dunes had badly cut faces and flanks, even though many dunes still carried a considerable cover of scrub. Coast spinifex, which is a native coloniser of the foredunes but also very palatable to stock and wildlife, had almost disappeared from many parts of the coast. Over the next ten years or more many of the 'cut faces' developed into blow-outs, then lengthened into long sand blows which coalesced into extensive bare sand masses covering everything in their path. Later, when fires and grazing pressures diminished and Tasmania experienced some better seasons with less wind and more rain, many of the smaller bare areas disappeared under vegetation again.

In Tasmania we are lucky to have good aerial photographic records of the coast since the late 1940s. Many of the changes described above can be traced by studying a sequence of aerial photographs and, from about 1990, Landsat imagery.

In what follows I give more examples and case histories, but first I should indicate the size and rate of movement of large sand drifts. Many sand blows and sand masses in the Northeast are more than a kilometre from front to back, and along much of that distance the sand may vary from 10-20 m deep and at times may exceed 35 m. A conservative estimate of the volume of a 1 m-wide west-east section of an average large sand blow 1 km long could be of the order of 15 000 m³:

$$\text{volume} = \text{length} \times \text{average depth} \times \text{width}$$
$$= \text{c. } 1\ 000 \times 15 \times 1$$
$$= \text{c. } 15\ 000 \text{ m}^3 \text{ per metre of frontage}$$

Longitudinal Dune Section

Area ABC ≅ ADEC
+ AFD
± EGC
≅ AFGC
= 1000 x 15

We can apply this figure to the sand blows at East Sandy Point as they were about 15 years ago (a. 1980) if we assume an average length of 1 km and use a figure of 700 m for the combined width of the sand blows. This gives a conservative estimate of 700 x 15 000 = 1 050 000 m³ of sand making its way to Anderson Bay, there to be washed around the coast towards Bridport. For comparison, the estuary at Bridport might have a high tide surface area of about 400 000 m² and a free water volume of about 650 000 m³ - no wonder the fishermen felt concerned!

The rate of advance of bare drifting dunes varies considerably and is affected by many factors including the following:

• velocity, duration and direction of sand-moving winds
• size, shape and mass of the sand particles
• sand moisture (damp sand has more cohesion)
• exposure and profile of the dune
• height of the advancing dune face
• dune roughness (which largely controls the surface wind velocity).

Land managers wishing to control dune movement generally aim to establish a good cover of vegetation, perhaps aided by brush fences, to minimise wind velocity at ground level. Apart from wind, the shape of a dune, especially the shape and height of the advancing front, constitutes the factor with the greatest influence on the rate of advance of a bare dune. A dune with a high, steep front moves forward slowly compared with a low, flat sand blow. Consider equal volumes of sand blowing over a dune face 20 m high and a sand blow 0.2 m deep. Twenty cubic metres going over the former would advance the dune only 1 m. The same volume blowing off a sand blow only 20 cm deep would extend the front 100 m. Sand will also blow straight across a bare flat such as the bed of a dry lagoon and will then accumulate on the first barrier it encounters beyond. Two to twenty metres a year might be expected for the rate of advance of a moderately high dune. On the other hand, low-fronted sand blows have often been observed to move more than 100 m in a year. One sand blow at Waterhouse swept across nearly 400 m of new pasture during the winter and spring of 1955.

Case histories

General

The first case study is on a grand scale: the movement of sand along the Northeast coast from Low Head to Musselroe Point. This coast-long movement of sand is less obvious now than it was 35 years ago when there were broken dunes and sand blows all along the way. Beaches oriented west to east were backed by dunes which increased in height towards the east and sand blows streamed inland where the beaches curved northwards. Behind west-facing beaches rose high frontal dunes with blow-outs and sand blows streaming eastwards. At headlands such as Five Mile Bluff, West and East Sandy Points, Waterhouse Point and Tomahawk Point, sand blows, past and present, could be traced right across the headlands and into the next bay to the east. At Five Mile Bluff in the 1960s sand used to pour off a high dolerite cliff into the sea. There was no sizeable beach below the cliff, but on the east side of the bay was a beautiful example of a rapidly growing young foredune. It was covered not with scrub, but with a vigorously growing mixture of grasses - spinifex, marram, and the prickly native dune grass (*Austrofestuca littoralis*). The dune was obviously both prograding and growing in height as was the foredune eastwards to Beechford and beyond.

At West Sandy Point sand blows extended from the western shore across the headland to pour onto the secluded beach of St Albans Bay. One sand blow tracked along the crest of the foredune for some distance before spilling onto the beach. Further along it blocked the outlet drain from Jerusalem Plains. The outlet had to be opened each winter by a bulldozer. On the east side of the bay, sand blows were making their way across East Sandy Point towards Anderson Bay. The system of moving sand thus went along and around bays and around and over the headlands or ran inland from lee shores. On aerial photographs or on the ground the system could be followed to Cape Portland and Musselroe Point.

At Bridport there is a series of popular little bathing beaches separated by rocky points and well-sheltered from west and northwest winds. In the 1950s and 1960s there were often complaints that the beaches were 'not like they used to be' because the sand was being washed away. At that time Bridport residents seemed unaware of the saga of sand movement around the coast, although the evidence was there to be seen. There had been no large injection of sand into the bay at East Sandy Point for years so the Bridport beaches were being starved. However, as mentioned earlier, during the 1970s the beaches improved again - but the port suffered! The beaches should remain in fairly good shape for some years to come, but a progressive decline can be expected thereafter. However, sand is accumulating west of the

Brid River training wall. In the future tourism may justify the expense of transporting this sand to nourish Bridport's beaches to the north. It is also conceivable that future coast managers might release a new supply of sand by stripping the vegetation off a dune at East Sandy Point and letting wind and waves do their work once again!

Saltwood

At the Saltwood property northeast of Little Piper River there are some lagoons and swamps that have been pushed back by encroaching dunes. As the dunes have moved into the deep western end of the lagoons the water bodies have been forced back up the gently sloping ground to the east and at the same time the water level has risen considerably. The most striking evidence of this process is the white skeletons of old eucalypts standing up out of the lagoons, much as they do in some man-made reservoirs, but the open lagoons have also diminished in size over the years and sadly it is the deep western ends that have gone. Coastal dune-impounded lagoons more than 2 m deep are becoming rare in Tasmania these days.

Cape Portland

The Tregaron Lagoons and associated dunes on the Cape Portland property of Hugh Mills also have an interesting history. The area is now a gazetted wildlife reserve under the National Parks and Wildlife Act. It is said that in the early days (late 1800s?) the lagoons were drained and cropped with barley. Certainly these days it would not be very difficult to drain most of these lagoons southwards and then westwards to the sea near Petal Point. However, in the early 1950s the lagoons were full and made a beautiful scene. They also appeared to present a safe barrier against the massive sand blows to the west. After working at Cape Portland in 1952 and 1953 I did not return until some time in the 1960s when I was shocked to see very active sand blows streaming up the paddock east of the lagoons. It turned out that in a couple of dry windy seasons the shallow lagoons had dried out and sand had blown straight across the flat bottom and up onto the paddock. Using a bulldozer Mills had dragged large boxthorn bushes and laid them in line as a series of north-south barriers across the sand blows, and marram grass has been planted between the barriers. This was very effective in checking the further eastward drift of the sand which has now accumulated as a new dune over the barriers and marram grass. Wet seasons followed and the lagoons filled again. Since then sand has crossed the lagoons or moved east between them on occasions but is generally fairly well controlled. The dune over the boxthorn barriers has now risen to a height of 15-20 m and is still growing, but marram grass, native tussock grass and native shrubs are stabilising most of it. The year 1994-95 was a very dry season. The Tregaron Lagoons dried out again and recently one small sand blow broke through. It is running out into the paddock again and will need treatment very soon.

Ringarooma Tier

South of the Cape Portland property and west of the Cape Portland Road rises Ringarooma Tier, a dolerite ridge 2-3 km inland from the sea and up to 120-150 m in elevation. In 1952 the tips of two big sand blows were just visible on the skyline from the Cape Portland Road. Now, just over 40 years later, two sand blows are a kilometre or more down the eastern slope. One is still pushing its way over the she-oak/eucalypt bush 5-7 m tall, while the other has reached the edge of the pastures. On the top of the tier a few white skeletons of trees stand forlorn among dolerite boulders while the lower western slopes are growing up again with scrub.

Big Waterhouse Lake

Big Waterhouse Lake is the largest of the lagoons at Waterhouse and still contains some quite deep sections - probably exceeding 2 m in depth. Besides some farm drains, Big Lake is also supplied by Sheepwash Creek, one of the few permanent creeks in the Waterhouse area. It is also one of the few lagoons with an outlet creek to the sea, though the lagoon does not spill into the creek all the year round. Much of the time the creek is fed by seepage through the sand. However, in the wet year 1964, the level of Big Lake rose and stayed high for weeks. There were signs that sections of the bare dune damming the lake next to the outlet creek might liquify and collapse, so an effort was made to bulldoze down enough sand to reduce the rate of seepage and contain the lagoon. Then more heavy rains fell and the outlet creek could not release the flood fast enough. The water rose further and ultimately the sand gave way. The waters poured out, scouring a canyon to the beach over a kilometre away. Next morning eels, trout, 'fresh water flathead' and other fish were strewn along the sand flats down to the beach. Gulls were feasting and some fish were still flapping about. The lagoon was almost empty. Later, when the country was drier, the outlet was repaired and a simple weir constructed with sand bags and scrub. The water level rose again to some extent - but not far enough. During the next summer while the water level was still low, dry westerly winds drove a sand blow right across the bed of the lake and up onto a paddock on the other side. Eventually the lake filled to its normal level and a kilometre of water again separated the sand blow from the pastures. In 1991 Big Lake broke out again, this time through a narrow vegetated ridge near the northwest corner of the lake (the normal outlet is in the southwest corner). Although a lot of water escaped and cut a channel through the dune ridges, the lake was not completely drained. Water ponded to make two or three new lagoons northwest of Big Lake, but these seem to be transient water bodies. The flow down the new water course is inadequate to keep them topped up regularly. It is interesting that one of these new lagoons, located well down towards the beach, occupied what had previously been a dry hollow filled with coast wattle. The wattles were killed and it will be interesting to watch the natural

revegetation of this hollow and changes in the vegetation of the other new wetlands up towards Big Lake.

It is tempting to 'play God' again and reinforce the break-away point beside the lake. Whilst it would be interesting to leave the system alone and monitor developments it should be remembered that Big Lake is the deepest lagoon at Waterhouse, is a significant waterfowl habitat and trout water, and that it is used as a farm water supply. Also, importantly, it protects valuable pastures from a large sandblow.

Another feature of Big Lake is the point of entry of Sheepwash Creek. Some years ago 'stream improvement' work on the adjoining property got out of hand. The creek scoured out a small canyon and the eroded sand was deposited as a delta flat in the lake. The flat was colonised by reeds (*Phragmites australis*). Nearby, along the southern shore of the lake, a small sand blow feeds sand to the delta when the lake level is down a little. Wind-blown sand lodges in the reeds and has raised the ground level steadily in recent years. More recently the area has been colonised by *Carex pumila*, *Spinifex sericeus* and *Acacia sophorae*. The site now stands about 2 m above the water and Sheepwash Creek has to find its way around this growing hillock.

Observations on coastal vegetation

Seasonal conditions influence the depth of free water or the height of the water table in a wetland and this, in turn, can influence the occurrence and distribution of various plant species in it. The depth of a wetland or parts of it can also be affected by other factors which may operate in dry seasons. For instance, rabbits and wombats will often 'cultivate' considerable areas of dried-out wetland in their search for succulent roots. A subsequent long, dry and windy period can result in a blowout which becomes a deeper hole within the wetland when water returns. Such holes are likely to be colonised by plant species differing from those in the surrounding shallows. If a fire gets into dry peat during a prolonged drought, the wetland may be deepened considerably and the lagoon rejuvenated.

As a big sand dune migrates eastwards it leaves bare ground behind to the west. The elevation of this bare ground corresponds with the height of the water table at the time and this level is soon fixed by natural revegetation. In wet periods the water table is high and this high level is fixed by pioneer species such as *Carex pumila*. If there follows a series of dry windy seasons the water table falls and the newly-exposed sand flat left by the drifting dune is eroded down to a lower level than before. This lower zone is also fixed by the colonising vegetation such as *Carex*, while the adjoining zone of higher ground to the west is likely to be invaded by coast wattle (*Acacia sophorae*). Observing a large deflation flat west of drifting dunes years later one may see alternating bands of coast wattle and sedgeland curving around marking the former locations of the windward edge of the

dune; the bands of *Acacia* on the higher ground correspond with wetter periods while the bands of sedgeland in the lower zones represent dry periods. The difference in elevation of the 'highs' and 'lows' may vary up to 600 mm or more. The banding often shows up well on aerial photographs. After many years the *Acacia* scrub may spread over most of the flat and the ridges and troughs may no longer be discernible on aerial photographs. Then a very wet period may flood the flat and kill the *Acacia*. Ridge formation on the deflation flats seems to be less conspicuous as the bare dunes are revegetated. The water table of the flats is augmented by seepage from the dunes, so if dune vegetation intercepts a lot of moisture the supply to the flats will be lessened and this would favour a spread of the *Acacia* scrub. It would be interesting to survey accurate west-east profiles of such flats and try to correlate the land forms with climatic records, particularly rainfall and wind, and to compare flats near large bare dunes with others adjoining stabilised dunes.

The sand sedge (*Carex pumila*) is a valuable native pioneer and colonist of wet sand flats from the salt spray zone at creek outlets to young wet flats well in from the sea. Once established, *Carex* will collect wind-blown sand and continue to grow upwards, easily raising the sand 2-3 m above the water table. Coast wattle may invade the *Carex* once the site has been raised sufficiently above the water table and the two species can co-exist for years, often being joined by other sedges, herbs and shrubs. Some efforts have been made to use sand sedge in reclamation works in the Northeast but so far the results have not been very encouraging. Nevertheless, the species is worth more trials.

Spinifex sericeus is a valuable native dune grass. It is particularly suited to foredune habitats but is also a useful pioneer and sand-binding species on dune sites well away from the sea. *Spinifex* is much used for dune stabilisation in Queensland and New South Wales where, apparently, it can be propagated fairly easily by vegetative means. In Tasmania, however, most field trials using *Spinifex* cuttings have been disappointing - perhaps because the species is near the limit of its range in Tasmania. On the other hand, the species can be readily introduced by seeding, and in situations where it is growing beside a sand blow it can be coaxed to spread by laying protective lines of brush out from the existing plants. *Spinifex* is very palatable to sheep and cattle and because of its surface running habit, it is easily damaged by trampling and vehicle traffic. These attributes have led to its decline and destruction in many places around Tasmania, including the Northeast. However, with the removal of stock the grass has shown a good recovery in many places. The year 1993-94 seemed to be a particularly good year for *Spinifex* around the Northeast and East coasts. Sadly, this beautiful grass is intolerant of human recreation pressures and will not regenerate extensively on popular beaches unless the foredune zone is fenced off.

Marram grass (*Ammophila arenaria*) is a European beach grass which has been widely used for beach protection and dune stabilisation on temperate coasts around the world. It is very hardy, easy to propagate and can withstand a lot of visitor pressure. It can also provide useful stock feed and thrives on winter/spring burning. These days it is becoming fashionable to brand marram grass as an environmental weed. I believe that as a generalisation this is too harsh a judgement, although there are times and places where its use could be avoided or where its invasion of a shore should be discouraged.

Bird observers have reported that oyster catchers and other shore-nesting birds tend to vacate beaches where marram grass has replaced the native grasses. However, for years I saw oyster catchers successfully raising their young on sections of Waterhouse Beach where *Spinifex* was absent and the foredune was clothed with marram grass. There are also numerous examples of native shrubs and other species recolonising dunes stabilised by marram grass, and in the last few years *Spinifex* has invaded marram grass very successfully on foredunes in the Northeast and elsewhere.

Conclusion

In concluding I would like to mention another very significant impact of western technology and land use on the environment of the Northeast. This is the effect of tin mining - mostly alluvial mining by sluicing and dredging - on catchments, rivers, wetlands and estuaries. There was much tin mining in the Northeast from the middle of the nineteenth century to the 1960s. In the tin-bearing districts, rich river flats and sloping catchments were worked over and left in a raw, derelict condition. Many such areas are still bare and eroding and they aggravate the flooding of streams and rivers. Huge volumes of soil and tailings went into the rivers. Fish and other life were killed and the rivers were left sterile. River beds were choked with gravel and sand which still is shifted down stream in pulses with each big flood. Bridges have had to be raised to clear the rivers and huge volumes of sand have spilled into estuaries often making them unnavigable. The old port of Boobyalla is land-locked by tailings from the Ringarooma River, while Medeas Cove at St Helens is nearly choked up and a massive delta of gravel is pushing out of George River into 20 m of water in Georges Bay. These are some of the hidden costs of mining. Who will pay, and when?

We are now half way through the Decade of Landcare. The next five years will not see all our catchments and dunes rehabilitated, nor all our rivers and coasts cleaned up. Let us hope that the message and spirit of Landcare do at least take firm root and that we treat our land better in the future than we have over the past two hundred years.

Relevant reading

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Environmental Changes in Northeast Tasmania during the Holocene

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Abstract

Pollen analyses from a number of bogs in northeast Tasmania demonstrate that the effects of climate, soil change, sea-level fluctuations, fire and land clearances have all played their part in determining the present-day landscape. At sea level, a treeless heathland is shown to have been a *Eucalyptus* forest before 6 000 BP, and before that a grassland. At 1 000 m elevation, Aboriginal burning appears to have created a number of openings in dense rainforest c. 1 500 BP. Elsewhere, the understoreys of extensive *Eucalyptus* forests changed in response to climate change and Aboriginal burning pressures over at least the past 4 000 years.

Introduction

During most of the Pleistocene, environmental changes in northeast Tasmania were driven by climatic forces most clearly expressed as a series of glacial/interglacial cycles. However, the dolerite plateaux and mountains which dominate the present-day landscape of northeast Tasmania were only minimally affected during the last glaciation from between 120 000 years BP (before present) to 10 000 years BP (Caine 1978, 1983). The most intensely cold phase of the Last Glacial occurred about 18 000 BP. At that time, mean annual temperatures were lowered by about 5 to 8 degrees. There was also a considerable reduction in mean annual precipitation (Macphail 1979). Under these conditions, and using a conservative lapse rate of 0.6 degrees per 100 m, the treeline would have been depressed to at least the 600 m level. Many landscapes and plant communities must therefore have been severely affected by the climatic deterioration.

In the dolerite high country above 1 000 m, radiocarbon dating of organic material trapped in blockfields and solifluction deposits shows that even though the great bulk of periglacial deposits was produced during the Pleistocene, a significant amount of material was mobile during the Holocene at about 3 500-2 500 BP (Caine 1978, 1983). This activity may be linked to either lowered temperatures, higher levels of precipitation, a more active fire regime or a combination of all three factors. There is little evidence to support an increase in precipitation but evidence from growth patterns of speleothems in the Mole Creek area (Goede & Hitchman 1983, Goede et al. 1990) suggests a temperature depression at about 3 500 BP of up to 2 degrees compared with modern conditions. There is also good archaeological evidence to suggest that Aboriginal activity in the highlands of Tasmania increased sometime around 3 000 BP (Cosgrove 1990, Thomas 1992).

At lower altitudes, the great sandy plains of northern Tasmania shelve gently into Bass Strait (fig. 1). Much of this transitional landscape formed part
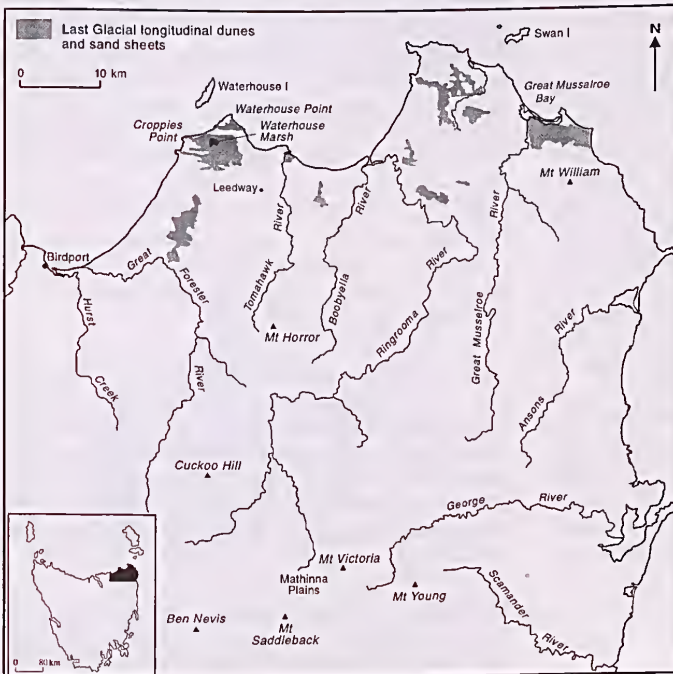

Fig. 1. Locality map for sites discussed in this paper.

of the Bassian Plain during the Last Glacial. The evidence contained in the dune sediments points to a succession of depositional events relating to sea-level changes, beginning with sand sheets laid down during marine transgressions and concluding with the early Holocene build-up of source-bordering dunes on the eastern margins of lagoons and parabolic dune systems along the coast. The intervening period encompassing the Last Glacial maximum was marked by the formation of a series of longitudinal dunes which extended across the Bassian Plain from the mainland into north Tasmania. At that time, climates were markedly colder and windier than at present (Bowden 1981, 1983). The formation of Bass Strait eventually isolated the dune fields and mobilised fresh sediment to eventually form the parabolic and transverse dune systems which today form the backdrop to the northeast Tasmanian beaches.

In areas dominated by aeolian landforms, the effects of human settlement on the environment probably became increasingly important through the mid- to late Holocene. As sea levels rose from around 10 000 BP, Aboriginal demographic patterns and economic objectives would have adjusted to a changing coastline until sea levels stabilised at about 6 000 BP. The favourable conjunction of marine, estuarine, lacustrine and terrestrial ecosystems which existed after 6 000 BP would have tended to focus settlement on inherently unstable aeolian landforms.

The coastal lowlands

The best evidence we have for environmental changes in the Northeast comes from a number of pollen cores extracted from wetlands on the coast, the hinterland and in the mountains. The near-coastal wetland of Waterhouse Marsh in the Waterhouse Point Protected Area documents a record extending from nearly 11 000 BP to the present. Surrounding the marsh are extensive treeless heaths on sandsheets dominated by *Allocasuarina monilifera*, *Xanthorrhoea* spp. and *Banksia marginata* and a large number of shrubs, especially those in the families Fabaceae, Dilleniaceae, Epacridaceae, Poaceae, Restionaceae and Cyperaceae (Kirkpatrick 1977). The wetland vegetation is characterised by the tall sedge *Baumea arthrophylla* and provides ideal conditions for the preservation of pollen. A core for pollen analysis was taken from the marsh which provides good evidence for local and regional vegetation changes from the late Pleistocene and through the Holocene. A date of 10 480 BP was obtained from root-free peat at the base of one metre of highly organic sediment. Just below this level, in clay-rich sediment, were large numbers of the mollusc *Coxiella striata* and fruits of the salt marsh obligate *Ruppia megacarpa*. On this evidence, saline conditions were present at 10 500 BP. After that time the marsh developed into a permanent, deep, freshwater wetland.

Vegetation

Changes in the relative frequency of *Nothofagus* pollen from Waterhouse Marsh (fig. 2) indicate a late phase of rainforest expansion in the Northeast, beginning prior to 6 500 BP before tailing off in the very late Holocene. Although some of this trend may be an artefact of the pollen percentage computations, a comparison with a pollen concentration diagram (Thomas 1992) suggests that the trend is real. On Flinders Island, *Nothofagus* pollen only becomes significant after 5 900 BP (Ladd et al. 1992), a time which closely agrees with the Waterhouse data and which suggests that rainforests in northeast Tasmania, and perhaps even southeast Victoria, expanded some time later than their west Tasmanian counterparts (Colhoun et al. 1990).

The survival of relictual pockets of rainforest in east Tasmania during the arid Last Glacial phase is interesting and can be attributed to the presence of a number of sites which provided suitable microclimatic habitats. Another reason may be that during the Last Glacial maximum, an extension of the warm East Australian Current flowing further south than is now the case would have moderated temperature and levels of aridity in east Tasmania. In Victoria, a similar explanation has been proposed to explain the survival of rainforests through the maximum of the Last Glacial (Burbidge 1960, Kenyon 1991).

Four significant changes occurred in the plant communities of the Waterhouse area over the Holocene. The first was a change from an open Asteraceae-rich grassland to forest dominated by *Eucalyptus*. The grassland taxa are typical of those commonly found at high altitude today and which probably existed across most of Tasmania during the Last Glacial. The suddenness of the transition from grassland to forest points to a rapid climatic amelioration at the start of the Holocene with mean annual temperatures rising above 10°C for the first time in at least 10 000 years. A number of pollen analyses in the Waterhouse area (Thomas 1992) hint that forests may have existed in selected locations as early as or earlier than 13 000 BP. Gains by forests at the start of the Holocene may thus have been characterised by the coalescence of isolated forest copses and increases in structural complexity, rather than the progression of a single wave of expansion.

The second major vegetation change was a transition from a grass-dominated ground layer to a heathy sclerophyllous understorey at c. 6 500 BP. This trend is indicative of a degradation sequence characterised by natural losses in soil fertility. The development of the podsolic soil profiles which are today so common in the sandy soils of the Northeast probably stems from this period.

The third major change is the loss of *Eucalyptus* forest at about 6 000 BP. This change coincides with the stabilisation of Bass Strait at present-day sea levels and

Fig. 2. Pollen abundance diagram for Waterhouse Marsh (selected taxa).

Fig. 3. Pollen abundance diagram for Forester Marsh (selected taxa).

Fig. 4. Pollen abundance diagram for Mathinna Plains (selected taxa).

the occupation of the Waterhouse Marsh environs by Aborigines. Considering the treeless heaths which dominate the area today, it is remarkable that extensive grassland and then forests should have existed there at various times through the Holocene.

The fourth major change is an increase in grass pollen in the upper levels of the core which coincides with the first appearance of exotic pollen. This phase marks the destruction of large areas of heathland and heathy woodland for agricultural purposes and the beginning of a period of landscape degradation which is still occurring.

Podsolisation

Acting with climate change in the sandy environments of the Northeast would have been a decline in soil fertility and a possible increase in waterlogging as podsolisation progressed (Bowden 1981, 1983). The gradual replacement of herbaceous grassland taxa by sclerophyllous shrubs, especially the Epacridaceae and Fabaceae, is evidence of a trend towards the development of heaths.

Post-glacial sea levels

Increased precipitation from about 10 000 BP along with sea-level rises would have allowed the recharging of aquifers and the raising of local water tables. This had the effect of stimulating organic deposition within basins and allowing the establishment of forests on sites which had previously been occupied by grassland. Post-glacial sea levels achieved a general worldwide stability sometime about 6 000 to 6 500 BP (Chappell 1990, Chappell & Shackleton 1986, Chappell & Thom 1977, Shackleton & Opdyke 1973, Thom & Roy 1985). This event may have directed the shift from *Eucalyptus* to *Allocasuarina* through the combined effects of disturbance by people and salt spray effects on vegetation.

The effects of fire

It is highly unlikely that fire by itself could have eliminated *Eucalyptus* forests from the study site. Fire would have had to occur consistently at an extremely high frequency to prevent seed production and this would have to occur over the 400-year lifespan of individuals. The heterogeneity of fuel levels in eucalypt forests usually allows regeneration to occur even in frequently burned stands. However, in exceptional circumstances, eucalypts can be eliminated by lack of fire on dry sites and can be replaced by *Allocasuarina* (Kirkpatrick & Marks 1986). In dry areas such as Waterhouse Point, reductions in eucalypt abundances can more probably be related to the synergistic interactions of fire, soil fertility and salt spray. Fresh epicormic leaves on fire-defoliated trees have no defence against salt spray. In addition there is a lack of protection from surrounding trees as well as an increasing rate of soil depletion (Kirkpatrick 1977). This mechanism for forest destruction can occur with either high or low fire frequencies.

Aboriginal occupation

Dates obtained for sand mobilisation at ca. 6 000 BP also define a period of Aboriginal site formation, which is almost certainly associated with a shift in the littoral zone to the vicinity of the study site (Thomas 1992). For Aborigines, the Waterhouse area probably shifted from a typical inland sclerophyll forest with poor supplies of fresh water to a near-coastal heathland with an abundance of potable water.

On the margins of Waterhouse Marsh massive numbers of artefacts are presently eroding from soil horizons which have been dated to about 6 000 BP. It is highly likely that sand was redistributed as sea levels stabilised at about 6 000 BP. It is also likely that local burning in combination with physical disturbances caused by Aboriginal occupation destabilised the erodible upper horizons of dune soils. This time corresponds to the major vegetation shift from *Eucalyptus* to *Allocasuarina*-dominated plant communities.

Bass Strait itself would have brought a new focus to Aboriginal economic objectives by providing a dependable marine resource base. An increased fire frequency is likely to have resulted. Cultural and climatic processes appear to have acted synergistically with long-term soil changes in the development of heathy understoreys and heathlands.

The hinterland

Pollen evidence from a sediment core taken from an unnamed marsh near the Forester River north of Scottsdale illustrates an important point in regard to the recent environmental history of northeast Tasmanian forests (fig. 3). Dry sclerophyll *Eucalyptus* forest very similar to that which exists today has existed in the region for at least 4 000 years. The origin of organic sediment in this deposit is probably related to increases in available moisture c. 4 500 BP which led to favourable conditions for the accumulation of sedge peat.

Carbonised particle values are high for the entire period of 4 000 years with no indication of canopy changes induced by fire. The major changes are in the understorey and wetland taxa, the most obvious being a dramatic increase in *Sphagnum* spores coincident with increases in *Nothofagus* and *Phyllocladus* and decreases in *Eucalyptus*. The most parsimonious explanation for these changes is that a cooling phase between 4 000 and 3 000 BP reduced evaporative losses and increased the effectiveness of surface moisture, thus allowing mesophytic and wetland taxa to expand.

An important point is that burning maintained heathy understoreys over a long period of time. We have some indication from ethnohistoric sources (Plomley 1966, Thomas 1994) that heathy vegetation provided an abundance of animal and vegetable resources for

Aborigines. In this case a well-established burning regime maintained a heathy rather than grassy ecosystem. What can be said is that the long-term burning of the northeast Tasmanian hinterland resulted in an environment which has remained relatively stable for at least 4 000 years.

The uplands

An intriguing short sediment core taken from a buttongrass moorland at 1 000 m in the northeast Tasmanian highlands provides direct evidence of local vegetation changes and strong circumstantial evidence to implicate Aboriginal burning as the agent for change (fig. 4). The site, on the Mathinna Plains, is presently dominated by *Gymnoschoenus* moorland surrounded by rainforest growing on sandstone. Pollen percentages suggest that at the time of initiation of organic deposition at 1 600 BP, forest was the surrounding vegetation. The most interesting trends show initially high percentages for *Sphagnum* spores and correspondingly low values for *Gymnoschoenus* pollen.

Organic accumulation was initiated either because climate changed sufficiently to allow mire formation or local hydrology changed in response to other factors. There is presently no evidence for climate change at 1 600 BP from any part of Tasmania, although this may be an artefact of a lack of research interest in the Holocene. There is, however, a general agreement that Aborigines in Tasmania probably burnt and maintained areas of forest and buttongrass moorland for socio-economic purposes (Jackson 1968, Macphail 1979, Jarman et al. 1988). Repeated burning by Aborigines could easily have removed fire-sensitive rainforest, raised water tables and created open-structured plant communities. A remarkably similar set of anthropogenic processes has been shown to have created grassland and *Sphagnum* bogs from rainforest some 200 to 300 years ago at Paradise Plains, just 5 km west of Mathinna Plains (Ellis 1985, Ellis & Thomas 1988).

It is important to note that for some centuries after the inception of organic accumulation, the dominant community was a *Sphagnum/Astelia* assemblage and not the *Gymnoschoenus* moorland we see today. The long gap in human terms between the inception of *Sphagnum* accumulation and the formation of true buttongrass moorland leads one to question if the creation of moorland was the original aim of burning. Perhaps Aborigines were trying to create *Sphagnum* communities or some other type of open vegetation. Perhaps the important factor to Aborigines was the fire itself or the act of burning and not the resultant effects. The possibility arising from this core is that we may have, in some instances, misinterpreted events from the deep past based on faulty analogies with ethnohistoric accounts and present-day plant communities.

Archaeological excavations and a pollen analysis from rockshelters situated on the margins of the buttongrass moorland of Mathinna Plains show that the date of the initial human occupation was close to 1 500 BP. The basal date for the onset of organic accumulation in adjacent buttongrass peat of Mathinna Plains is 1 600 BP. The dates are statistically identical at two standard deviations. Perhaps the peat date merely represents the latest phase in a cycle of bog development, but in consideration of the archaeological data, it more likely links Aboriginal burning practices with the actual creation of buttongrass moorland from forest.

Conclusions

Northeast Tasmania has experienced many environmental changes over the 10 000 year span of the Holocene. Some of these, such as warming climates at the end of the Last Glacial, are globally expressed. Others, such as the response of vegetation to pressures caused by Aboriginal influences, may or may not be unique. Only further research will tell.

The Holocene has traditionally been seen as a period of mild rather than dramatic change. In contrast, the Pleistocene is viewed as a tumultuous series of glacial/interglacial cycles characterised by constant environmental changes. The history of northeast Tasmania shows that environmental change in the Holocene was neither uniform nor necessarily mild. Shifts in the vegetation of the northeast Tasmanian lowlands from open grassy communities to *Eucalyptus* forest and then to treeless heaths are as dramatic as any which occurred earlier.

The apparently late expansion of rainforests in the Northeast means that inland plant communities were responding to unique environmental circumstances well after west Tasmanian rainforests had established their maximum range in the early to mid-Holocene. It may even be that ecosystems in the Northeast have not yet equilibrated with climatic circumstances caused by the formation of Bass Strait.

Other plant communities, especially the dry sclerophyll flora, appear to have more in common with mainland Australian systems than anything which is usually labelled Tasmanian. Northeast Tasmanian environments therefore have the capacity to illuminate connections with mainland Australia as well as with the ancient Gondwana relicts of west Tasmania.

Unfortunately, the ecologically detrimental effects of development activities threaten our ability to understand these processes of change. We are beginning to know what happened after global warming some 10 000 years ago. That understanding, if pursued vigorously by further research, would undoubtedly provide insights into what may happen under the present-day threat of anthropogenic global warming. If we take seriously the heritage which is contained in the landscapes of northeast Tasmania we must also seriously question the rationality

of land management regimes, including farming and forestry, which threaten to rob us of our ability to address that heritage and our future.

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Botany

The Flora of the Wetlands of Northeast Tasmania

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Abstract

A study of wetlands in northeast Tasmania revealed the presence of many rare or threatened native plants. The features of wetlands plants and details of selected wetlands are discussed. The importance of wetland ecosystems and reasons for ensuring their existence are stressed.

Introduction

Studies carried out by the author and D. Steane between 1990 and 1994 under the auspices of the Plomley Foundation and the Queen Victoria Museum and Art Gallery have provided further knowledge of the wetland vegetation of northeast Tasmania and brought to light several species which were not previously known to occur in the area. An earlier well-organised study by Kirkpatrick and Harwood (1983) had produced much information about the Tasmanian wetlands and one of its aims was to identify areas for conservation to ensure the survival of some unprotected native species. The purpose of the Plomley Foundation studies was different. It was to survey the wetlands between the Tamar River and St Helens in order to choose one or two of the most suitable for future biological studies of Tasmanian invertebrates and plants. For this reason most of the wetlands visited

Fig. 1. Location of wetlands featured in this paper.

(fig. 1) were surrounded by native vegetation although one or two abutted on improved pasture. All were on the coastal plain and in areas of land which had been protected for many years by private landowners or government departments. Not only the big water bodies such as Bowlers Lagoon, Blackmans Lagoon, Big Waterhouse Lake, Tregaron Lagoons and lagoons at Cape Naturaliste and St Helens were studied but also wet sedgelands, small ponds and seasonal lagoons in coastal heath in interdune swales. The water varied in salinity from fresh to brackish. Farm dams were excluded. For comparison, the estuary of the Little Musselroe River with its salt water and marine swamps was added to the

study. As might be expected from such a large area very many plant species were identified and recorded. Many were widespread, occurring in most wetlands, while a few were restricted to one lagoon or a group of lagoons in one area.

Ecological notes

Lakes and water bodies are not only for human use and enjoyment but are busy factories in which green algae and higher plants produce the basic sugars and starches of the food chain and concentrate other nutrients. These plants feed invertebrates, fish and birds and the edges are grazed by marsupials. Algae and aquatic plants are thus critical components of wetland ecosystems and of environmental stability.

There are many habits of growth in the aquatic plants. Some such as the Characeae and other algae grow and reproduce while totally submerged. Other plants float on the surface, as do *Lemna disperma* and *Wolffia* spp. Some are rooted in mud or sand and send only flowers to the surface, e.g. *Ruppia* spp., while others float leaves as well as flowers. Most macrophytes, however, are rooted in the substrate and bring leaves, stems and flower heads above the surface, e.g. *Triglochin* spp., *Villarsia* spp. and sedges.

Water plants tend to have structural features in common. They are generally light in construction, and many have air spaces or spongy tissue in leaves, stalks or culms. Some have stiffening fibres, others are kept stiff by cell turgor. They are nearly all herbaceous. They often grow close together in clumps or masses with rhizomes or roots matted together. Some aquatic plants store nutrients in tubers, others in fleshy roots. Pollination by insects is rare. In many cases the pollen is carried by wind and in a few species by water, e.g. *Lepilaena* sp. and *Zostera* sp.

These features are advantageous to survival, especially in times of drought. Since energy is not used in building up massive woody structures it can be used for production of flowers and seeds early in the growth cycle. Early seeding is an advantage where growing seasons are shortened by dry conditions. Lightly constructed flexible bodies can bend with water and wind movement, the thick root masses spread the tugging effect of wave action, the air spaces aid in flotation and gas exchange and the underground storage in tubers (*Triglochin procera*) and

Fig. 2. Bowlers Lagoon. Thick beds of *Villarsia reniformis*, *Triglochin procera*, *Baumea arthrophylla*, *Eleocharis sphacelata* and submerged aquatics fill the eastern end of the lagoon.

rhizomes (*Baumea* spp.) buried in mud aids survival in drought. Many of these plants have their flowers massed in heads, spikes or panicles, so with the aid of coastal breezes pollination is easily achieved and large quantities of seed are produced, e.g. *Typha* spp. (bull rush), *Phragmites australis* and sedges. Submerged aquatics also grow in crowded beds and produce many seeds or propagules, e.g. *Lepilaena* spp., *Chara* spp.

There are few woody native plants in northeast Tasmania which can grow all year round in water (*Melaleuca ericifolia*, *Leptospermum riparium* and *L. lanigerum* are examples), but many can grow at the edge of wetlands.

The full reports for the wetland studies of 1990-94, listed under References, are held at the Queen Victoria Museum and Art Gallery, where they may be consulted.
Some typical lagoons and wetlands will now be described (see fig. 1 for locations).

Bowlers Lagoon (grid reference EQ780760)

Bowlers Lagoon is situated about 2 km inland from Boobyalla Beach and west of Red Hills property. It lies in a hollow less than 10 m above sea level with coastal heath and scrub of *Acacia sophorae*, *Banksia marginata*, *Leptospermum lanigerum* and *Melaleuca* spp. at its eastern edge and sand flats and mobile dunes on the south, west and north.

The main lagoon (fig. 2) is about 1 m deep with some open water but in wet conditions it spreads extensively over the sand flats and deepens. In average seasons there is a mixed herbfield up to 5 m wide containing *Isolepis* sp., *Leptinella reptans* and *Neopaxia australasica* on part of the eastern shore, backed by *Melaleuca gibbosa*, *Acacia sophorae* and *Leptospermum laevigatum* and other scrub species on the bank and giving way to *Melaleuca ericifolia* stands at the southwest end. The lagoon contains much *Wolffia australiana* in the shallow water with a little *Lemna disperma* and *Utricularia australis*. The largest water plants are *Eleocharis*

sphacelata, *Baumea arthrophylla* and *Triglochin procera*.

In shallower water is a dense growth of *Villarsia reniformis*, *Myriophyllum salsugineum* and *M. simulans*, *Potamogeton tricarinatus* and numerous other species. A few plants of *Rumex bidens* (mud dock) and *Glyceria australis* are growing in this dense vegetation near where a small creek flows through the *Melaleuca ericifolia* from an adjoining sedgey lagoon. *Carex pumila* (sand sedge) and *Schoenoplectus pungens* are colonisers of the sandy flats below the dunes on the northern shore. Three species of *Chara* and two of *Nitella* were collected from shallow water. On an adjoining flat *Colobanthus apetalus* is colonising bare sand.

Jocks Lagoon (FQ093220)

This lagoon (fig. 3) is situated near St Helens between the coastal dunes of Marouard Beach and a ridge about 25 m high which is covered with small trees and heathland vegetation. Although some of the coastal dunes have bare sand at the top, their inland sides are vegetated. The lagoon has its long axis north-south. On the southern shore is a narrow sandy beach and a well established stand of *Melaleuca ericifolia* with *Lepidosperma longitudinale* and *Sphagnum falcatulum*. This species of *Sphagnum* is common around this lagoon and in others of the St Helens - Bay of Fires region.

Jocks Lagoon has more open water than Bowlers Lagoon and differs in having deeper water and very little floor vegetation. The dominant water plant in the southern end is *Eleocharis sphacelata* with *Triglochin procera* which extends northwards particularly on the eastern side (fig. 4). Large beds of *Baumea* spp. and *E. sphacelata* which are more extensive near the southern end grow along the middle and western side for about two-thirds of the distance. *Baumea articulata* grows with *Melaleuca ericifolia* where a small creek enters on the western side. North of this creek *Lepidosperma longitudinale* is abundant on the wet flat beside the lagoon with *Villarsia exaltata* and *V. reniformis*, both of which are also present in the lagoon itself. A fringe of *Leptocarpus tenax* extends

Fig. 3. Jocks Lagoon lies between the dunes of Marouard Beach and higher ground to the west. In wet seasons, water floods onto the flat at its northwest edge.

Fig. 4. *Triglochin procera* in Jocks Lagoon with *Baumea* spp. and *Eleocharis sphacelata* towards the far bank.

northward on the eroded bank to a small beach of white sand at the northern end. At the northeast corner a narrow channel opens to other water bodies full of *Baumea* sp. and *Villarsia* sp. The eastern bank is fringed for some distance with *Leptocarpus tenax* in front of a belt of scrub and trees of *Banksia marginata*, *Melaleuca ericifolia*, *M. squarrosa* and *Acacia sophorae*, and on drier ground *Bursaria spinosa* and *Eucalyptus viminalis*. This belt extends to the southern end where *M. ericifolia* becomes the dominant tree.

Shaft Lagoon (FQ095245)

Further north in Shaft Lagoon *Baumea articulata* was also found with *Chorizandra australis* and *Eleocharis sphacelata*. These three are difficult to tell apart in their non-flowering stage but the septa in the culms differ. *Lepyrodia muelleri* was recorded from several wetlands including Shaft Lagoon and Moriarty Lagoon (FQ099248) which also had *Schoenus brevifolius,* not found elsewhere in the wetland survey.

Waterhouse Protected Area

This coastal area, which includes Blackmans Lagoon, Big Waterhouse Lake, Little Waterhouse Lake and dunelands, coastal heathland and wet sedgelands, some to 2 km in length, has great diversity of vegetation. There are patches of light forest with eucalypts, *Banksia marginata*, *Monotoca elliptica*, *Bursaria spinosa* and hills covered with *Allocasuarina verticillata*, swamps surrounded by various *Melaleuca* species, heathlands with *Xanthorrhoea australis* and some patches of *Gymnoschoenus sphaerocephalus* (button grass). There are wetlands among the dunes, wetland plants in soaks and complex wetlands in low-lying areas.

One of these large, complex wetlands has several parts including a seasonal lagoon with water up to about 1 m deep, salt grass flats with *Zoysia macrantha* and *Distichlis distichophylla*, and another basin cut off by bands of *Melaleuca ericifolia* and scrub with *Monotoca* spp. and *Leptospermum* spp. This basin contains an almost pure stand of *Leptocarpus tenax*, while another

area is filled with *Gahnia trifida*. *Leptocarpus brownii* occurred in one spot at the lagoon edge.

The largest lagoon of the complex has *Baumea arthrophylla* and *Villarsia reniformis* as its dominant plants with *Triglochin procera*, *Schoenus fluitans*, *Myriophyllum salsugineum*, *Lepilaena cylindrocarpa* and *Potamogeton tricarinatus*. It is densely vegetated and contains *Lamprothamnium papulosum* and several *Chara* species. The dense growth of these is well seen from the dried remains when the lagoon is dry in summer. In wet seasons water spreads over the flats and into the secondary basins and small depressions. This was the only Waterhouse wetland where *Lawrencia spicata* was recorded. Two species of large *Baumea* may be present but fruit was not available to verify this.

Another wetland at Waterhouse in heathland has *Melaleuca gibbosa* with *Leptocarpus tenax* and *Lepidosperma longitudinale* in its fringe and *Xyris operculata* at the junction with heathland. In the wetter part are *Baumea arthrophylla*, *Chorizandra australis*, *Lepyrodia muelleri* and *Villarsia reniformis*.

Orchids including *Spiranthes australis*, *Microtis atrata*, *M. orbicularis*, *M. unifolia* and *M. parvifolia* were common in wet sedgey lagoons. In some wetlands *Triglochin striata* grows in dense beds while some others have *Typha latifolia* and *Phragmites australis* but usually in small patches. *Villarsia reniformis*, *Lepilaena* spp., *Triglochin procera*, *Eleocharis acuta*, *Mimulus repens*, *Utricularia australis*, *U. dichotoma*, *Ruppia polyantha* and Charads are commonly found in small ponds as well as in larger water bodies.

One lagoon near Big Waterhouse Lake has *Cladium procerum* which had not previously been recorded in Tasmania. The lagoon is in the path of an advancing dune and the plants are being covered with sand.

Cape Portland Estate and the Tregaron Lagoons

The four lagoons closest to the road to Petal Point around EQ815855 lie in a flat area and are separated by partial barriers formed by sand dunes moving eastward from the coast. When water is plentiful the lagoons are

Fig. 5. Dense cover of dead *Chara*, *Nitella* and *Lamprothamnium* species in a dry Tregaron Lagoon.

interconnected. In drought all are almost dry (fig. 5). The floors are densely vegetated with aquatic plants including *Villarsia reniformis*, *Triglochin procera*, *Ruppia polycarpa*, *Lepilaena* spp., *Myriophyllum salsugineum*, *M. simulans* and *M. muelleri*, *Ranunculus amphitrichus*, *Potamogeton pectinatus* and *Chara*, *Nitella* and *Lamprothamnium* species. Tussocks and bands of *Juncus* including *J. kraussii* and *Leptocarpus* sp. line the banks and water's edge, but in places herbfields with *Crassula helmsii*, *Liliaeopsis polyantha*, *Juncus articulatus* and *Mimulus repens* occur between the tussocks. The water is probably enriched by run-off from adjoining pastures and by the droppings of the many birds and marsupials which use the wetland. The more northern lagoons have a greater amount of free water than the southern.

North of these lagoons is another lagoon (EQ823870) southeast of Charmouth Hill which has a bare sandy floor beside a low dune ridge at its southern end. The northern end has a more silty sand and some aquatic vegetation of *Lepilaena* sp., *Ruppia polycarpa* and *Sarcocornia quinqueflora*. The northern shoreline has grassy turf on low banks with salt-tolerant species. *Sebaea albidiflora* and *Mimulus repens* are common in the turf and *Wilsonia rotundifolia* on a low bank. The parasitic *Cuscuta tasmanica* is found on plants in the turf beside the lagoon. In summer 1994-95 the lagoon is dry. The silty flats are being colonised by *Sarcocornia quinqueflora* and *Suaeda maritima* for some distance into the lagoon beyond the usual water line.

Northern wetlands on Cape Portland Estate

A line of small wetlands runs east-west between points EQ823888 and EQ851886 inland of the dunes facing Banks Strait. *Lepilaena cylindrocarpa* and *Ruppia polycarpa* occur in some. Another lagoon also contains *Myriophyllum muelleri*, *Lepilaena patentifolia*, *L. preissii*, and *Potamogeton pectinatus*. *Wilsonia humilis* and *W. rotundifolia* are found on salted flats with *Lawrencia spicata*. *Calocephalus lacteus* is scattered in the grassland.

Cape Naturaliste lagoons

The coastal lagoons between Musselroe township and Stumpys Bay which are shown on the Musselroe and Naturaliste 1:25 000 map sheets were visited and inspected. The two closest to Cape Naturaliste at FQ024772 and FQ024770 are joined and the big sedgeland to their west drains into them. The lagoons have open water and their principal aquatic plant is *Triglochin procera*, while the sedgeland has much *Chorizandra australis* and other large sedges. Several species of *Chara* and *Nitella* were collected.

The shallow lagoon on the Mt William National Park boundary at FQ005783 yielded several species of Charad. The lagoon dries out in summer.

Musselroe Point Lagoon (EQ994796) has a large

herbfield of *Sarcocornia quinqueflora* and *Lamprothamnium papulosum*; *Myriophyllum muelleri* was also recorded. The deepest part of the lagoon close to the coast contains several other Charads but the water was muddy and foul and no collections were made.

Top Camp Lagoon (FQ012779), which dries out completely, has an extensive herbfield and *Eleocharis sphacelata* is its largest aquatic. Other lagoons were inspected and photographed but since they have National Park protection their documentation was left for the time being, except for Top Camp Lagoon.

Little Musselroe estuary and salt marshes

The estuary of the Little Musselroe River (EQ874864) consists of a narrow estuarine section which opens into a shallow basin 1 km long and connects to the sea at its northern end by a narrow mouth. The basin has a flat sandy bottom and at high tide the water is less than 1 m deep. A narrow coastal strip cuts the estuary from Little Musselroe Bay on the north but this strip widens to the east beside the riverine section of the estuary. This land barely rises above sea level, its elevation being generally less than 3 m.

On the southern side of the estuary the salt flats are bounded by a low ridge about 20 m high crowned by *Allocasuarina verticillata* and with coastal scrub and small trees on its lower slopes.

Both sides of the estuary have extensive flats on which salt marshes inundated at high tide have developed (fig. 6). The main plants and those which are inundated for the longest period are *Sarcocornia quinqueflora* and *Sclerostegia arbuscula*. A little *Sarcocornia blackiana* is present also. The northern flats have ridges of slightly higher ground which divide them into sections or basins. Small channels which drain and replenish the marsh have formed in some.

Fig. 6. Little Musselroe. When the tide floods the salt marsh, some *Sclerostegia arbuscula* bushes remain emergent while the shorter *Sarcocornia quinqueflora* is covered.

Fig. 7. Little Musselroe at a junction of salt marsh and *Melaleuca ericifolia* fringe.

Many other salt-tolerant plants occur in the salt marsh, including *Samolus repens*, *Heurichroa pentandra*, *Distichlis distichophylla* and *Wilsonia backhousei* which all appear toward the seaward end of the marsh. There is a gradation in vegetation vertically as the land gradually rises and the duration of inundation decreases, and also (especially on the southern side of the estuary) a gradation outward from estuary to the base of a ridge, presumably caused by fresh water draining from higher land. *Disphyma crassifolia* appears on ridges in the seaward end of the northern marsh and in greater amounts higher up the southern marsh. Other plants include *Lawrencia spicata* on stable ground rather than on soft mud, and small herbs grow on the areas which are covered by salt water for short periods. These include *Angianthus preissianus*, *Wilsonia backhousei*, *Cotula reptans*, *Sebaea albidiflora* and *Lobelia alata*.

The salt grasses *Zoysia macrantha* and *Sporobolus virginicus* grow on the sand in the splash zone and on the edges of the salt marsh. Some plants of *Suaeda maritima* are also found at about this level. The vegetation bordering the marsh varies from place to place. At the seaward end *Rhagodia candolleana*, *Alyxia buxifolia*, *Monotoca* sp., *Leucopogon parviflorus* and *Stipa stipoides* are common. At the base of the ridge on the southern side, coastal scrub with *Kunzea ambigua*, *Acacia sophorae*, *Leptocarpus brownii*, *Gahnia filum*, *Leucopogon parviflorus*, *Poa* sp., *Danthonia* sp. is found and an occasional *Myoporum insulare* and she-oak. *Melaleuca ericifolia* stands have developed along the margin of the marsh, usually on slightly raised ground or where salt influence is reduced (fig. 7).

On the northern flats *Wilsonia rotundifolia* was recorded once on the upper marsh although *W. backhousei* is found on both northern and southern sides in sites of higher salinity. On the northern side the scrub barriers between marshes become wider with larger numbers of heathland plants. *Bauksia*, *Acacia sophorae* and *Melaleuca* thickets become more frequent and the open spaces are covered with salt grasses rather than with *Sarcocornia* until *Bauksia* mixed woodland becomes coastal heath at an

elevation of 3-5 m above sea level.

On the southern side *Sarcocornia quinqueflora* continues along the river at intervals and appears in some salted areas in paddocks. As fresh water replaces the salt and the tidal flow ceases, grasses, *Melaleuca ericifolia* and *Allocasuarina paludosa* appear until the riverine vegetation typical of fresh water streams is established.

The floor of the estuarine basin has *Zostera muelleri* as its only macrophyte. The bed is small and *Z. muelleri* also occurs in the wider channels in the salt marsh. *Ruppia polycarpa* was collected from the riverine section. The only Charad seen was in a wet area in pasture near the end of the estuary.

Significant results and new information

The wetlands surveys of 1990-1994 yielded several significant results as follows:

- *Cladium procerum*, known in mainland Australia but not recorded from Tasmania, has been collected from the Waterhouse Protected Area;

- *Myriophyllum muelleri* occurs in Big Waterhouse Lake, Cape Portland and Tregaron Lagoons and south of Policeman Point, Ansons Bay;

- *Wolffia australiana* is widespread in the Northeast;

- *Cuscuta tasmanica* was found at Cape Portland;

- *Utricularia australis* exists in lagoons from Waterhouse through to St Helens;

- *Baumea rubiginosa*, previously recorded from only two localities in Tasmania, was found with its orange fruits in mine tailings in the St Helens area;

- *Lepilaena preissii* occurs in some lagoons at Cape Portland;

- *Wilsonia humilis*, *W. backhousei* and *W. rotundifolia* are all in the Cape Portland area; and

- *Microtis orbicularis* has been located in several lagoons.

These, with the exception of *Wilsonia backhousei*, are rare or threatened plants in Tasmania.

During the last four years about 15 taxa of *Chara*, *Nitella* and *Lamprothamnium* have been located at various places in northeast Tasmania. Some are awaiting identification.

Concluding remarks

The survey has shown that northeast Tasmania has a rich flora and contains many species classed as rare or endangered. Many of these are associated with wetlands or soaks in heathland. The large Waterhouse Protected

Area with its diversity of sites has the largest number of rare species while additional rare species occur at Cape Portland and St Helens. The survival of such species depends on the continued existence of their habitats, consequently these wetlands need to be protected. Since all wetlands change with changing conditions of climate, weather and time, studies into their development and decay, and succession in the vegetation cover are important and worthy of study. Northeast Tasmania provides many areas where such research might be undertaken.

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A Brief Description of the Alpine Vegetation of Ben Lomond and Mt Barrow, and a Comparison with the Victorian Alps

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Abstract

The vegetation of the Ben Lomond plateau and Mt Barrow in northeast Tasmania is briefly described. Factors influencing the vegetation such as altitude, drainage, topography, aspect, soil, fire, periglacial features, glacial history and geology are discussed. The conspicuous absence of a number of plant species and communities in northeast Tasmania is noted. A brief comparison is made with the Victorian alps. It is suggested that the Ben Lomond plateau has experienced Tasmania's harshest and most continental climate (i.e., coldest, driest, windiest), which is reflected in the vegetation by the absence or reduced extent of a number of communities and species.

Introduction

Ben Lomond and Mt Barrow are prominent mountains in northeast Tasmania. They are located about 50 km southeast of Launceston and 25 km east of Launceston respectively. Both are plateaux of Jurassic dolerite. The Ben Lomond plateau is a roughly rectangular area of approximately 6 500 ha ranging in altitude from about 1 200 m to over 1 500 m. The northern half of the plateau generally maintains an altitude of over 1 400 m while the southern half ranges from 1 300-1 400 m. Legges Tor, at the northern end of the plateau, is the second highest point in Tasmania at 1 572 m. Stacks Bluff, at the southern end, has an altitude of 1 527 m. The Rodway Valley dissects the plateau and descends to an altitude of 1 240 m. A highly localised exposure of sedimentary rocks occurs under Coalmine Crag and on the south-facing slopes of the escarpment below Stacks Bluff and includes mudstone, sandstone, siltstone, hornfels and coal. Periglacial and localised glacial features are evident over most of the plateau. A small ice-cap once existed on Ben Lomond, which was the only area in northeast Tasmania to be glaciated (Caine 1983). The Mt Barrow plateau is also roughly rectangular and covers about 600 ha. Mt Barrow at 1 406 m is the highest point on the northern part of the plateau, with South Barrow the dominant feature at the southern end.

Previous botanical work on these mountains is limited. Kirkpatrick (1982) conducted a statewide phytogeographical analysis of alpine floras. He described a number of Tasmanian groups as well as a mountain mainland group containing Australian alps species. Most of these Australian alps species have been identified as having their national southern limit of range in the Central Highlands of Victoria at or near the Baw Baw plateau by the Australian Heritage Commission and Department of Conservation and Natural Resources (1994).

Summary of alpine vegetation types on Ben Lomond and Mt Barrow

The present paper summarises information presented in detail elsewhere (Davies & Davies 1989, 1990). Nomenclature follows Buchanan (1995) for Tasmanian species and Ross (1993) for Victorian species. The only exceptions are the Victorian taxa *Richea victoriana*, which has recently been separated by Menadue and Crowden (1995) from the Tasmanian endemic species *Richea gunnii*; *Monotoca oreophila*, which has been described by Albrecht (1995); and *Tasmannia vickeriana*, which has been recently described by Raleigh et al. (1995).

Nine vegetation types are briefly described below. These were identified from sampling at 1 km intervals along 73 km of strip-line survey across the Ben Lomond plateau and 500 m along traverse lines forming a grid system across the Mt Barrow plateau. The communities are ordered along a moisture gradient from rocky, well-drained areas such as scree deposits, to poorly drained, boggy sites. Species lists for the Ben Lomond plateau and Mt Barrow are provided in Appendix 1.

1. Dolerite boulderfield/scree

This vegetation type is found at Ben Lomond and at Mt Barrow and is characterised by large areas of soil-less habitat devoid of higher plants and colonised instead by lichens and mosses. Localised patches of multi-stemmed, high-altitude callidendrous rainforest (Jarman & Brown 1984) can develop on high-altitude scree deposits provided sufficient subterranean water is available, as the scree provides protection from fire even on dry, north-facing slopes. These periglacial features are far more extensive on Tasmanian dolerite mountains than in the Victorian alps. Where screes do occur in Victoria they are on basalt or rhyolite and tend to be dry, without the damp, mossy crevice habitats that in Tasmania may contain stunted small trees of *Nothofagus cunninghamii* and the ferns *Hymenophyllum peltatum* and *Grammitis*

poeppigiana.

2. Skeletal rock herbfield

This community was only recorded at Ben Lomond and occurs on sheets of glaciated dolerite pavement and on rocky outcrops. Most of the community consists of lichens. Shrubs are typically absent and higher plant species are restricted to skeletal soils within small cracks associated with cooling joints in the dolerite. This community occupies the most drought-prone and shallow-soiled habitat exploited by higher plants on the plateau. No species is typically dominant, but the herbs *Ewartia catipes*, *Oreomyrrhis eriopoda* and *Luzula* sp. are often present as scattered occurrences. Community 2 is closely related to community 3 (below), which occurs on jagged, rocky outcrops rather than smooth glaciated pavement.

3. Chionohebe ciliolata *rock cushion*

This community was only found on Ben Lomond at high altitude (1 520 m). It develops on extremely well-drained rocky areas on Stonjeks Lookout where the cushion-forming herb *Chionohebe ciliolata* occurs. Stonjeks Lookout is the only known location for the species in Australia. *C. ciliolata* has an internationally disjunct distribution, the only other localities being in New Zealand, where it occurs in subalpine fellfield and bare rocky areas on the west coast of the South Island. Cushions of *C. ciliolata* vary in size from about 5 to 40 cm in diameter and the species grows on drier sites than any other cushion-forming species in Tasmania. Die-back is evident in some of the larger cushions with up to half their foliage dead. Given its highly localised distribution in Tasmania, and the fact that it is not known whether the range of the species is expanding, contracting or static in Tasmania, the population should be monitored. The taxonomic status of *C. ciliolata* is also worthy of further study as it could actually be a Tasmanian endemic species that has been inadvertently grouped with the New Zealand taxon.

4. Neopaxia australasica *stony herbfield*

This community develops on sorted polygons of dolerite gravel and small stones, a periglacial feature that seems to be more evident on the Ben Lomond plateau than on other mountains in Tasmania. These areas are exclusively and sparsely colonised by the creeping perennial *Neopaxia australasica*.

5. Aquatic stonefield/herbfield (fens)

This community was only recorded on Ben Lomond. It typically includes the grass *Deschampsia cespitosa* and occupies areas of shallow stony soils subject to ephemeral ponding and cold air drainage. Water availability fluctuates markedly from waterlogged conditions associated with shallow ponding to droughty conditions when the pools evaporate. The sedges *Carpha alpina* and *Carex gaudichaudiana* are often also present. The group

is closely related to the *Neopaxia australasica* stony herbfield that develops on sorted polygons of dolerite gravel and small stones (community 4).

6. Richea scoparia - Empodisma minus - Poa gunnii *grassy shrubland*

This is the most widespread and common community on the Ben Lomond and Mt Barrow plateaux. It typically consists of shrubs of *Richea scoparia* and *Baeckea gunniauus* over a dense ground cover of *Empodisma minus* and *Poa gunnii*. It is common on valley floors and on moors.

7. Richea scoparia - Empodisma minus - Abrotanella forsteroides *cushion shrubland*

This community is typical of poorly drained areas or waterlogged sites on valley flats and moors on Ben Lomond. The dominant shrubs are *Richea scoparia* and the cushion-forming *Abrotanella forsteroides*. *Empodisma minus* and *Poa gunnii* are also often present.

8. Restio australis *cord-rushland*

This community was only found on the warmer southern end of the Ben Lomond plateau in highly localised areas of poor drainage close to gently sloping north-facing flats where cold-air drainage and snow-lie are less pronounced. The dominant species is *Restio australis* with *Empodisma minus* and clumps of *Astelia alpina* also present. The community is widespread on dolerite mountains in central Tasmania.

9. Gleichenia alpina *feruland*

This community was also found mainly on the southern part of the Ben Lomond plateau on the warmer, north-facing, gently sloping flats where cold-air drainage and snow-lie are less severe. The dominant species is the fern *Gleichenia alpina*. Other species typically present are *Astelia alpina*, *Empodisma minus* and *Poa gunnii*.

Ecology and Tasmanian biogeography

Special features of Mt Barrow vegetation

There are a number of features of the Mt Barrow vegetation that are special. It contains the only known high-altitude (subalpine) occurrence of the rare Tasmanian endemic, *Acacia axillaris*, where it grows under *Leptospermum lanigerum* scrub. Mt Barrow has perhaps the best developed example of callidendrous rainforest scrub developed on north-facing subalpine scree and talus deposits. Lastly it contains perhaps the highest-altitude occurrence of *Spyridium ulicinum* in alpine heath. This is an unusually hairy-leafed form and warrants further taxonomic work. It occurs outside the State Reserve in an area of State Forest.

The species listed in Table 1 were notably absent from the study areas on Mt Barrow and Ben Lomond plateau yet

Table 1. Species absent from Ben Lomond and Mt Barrow.

Trees	Shrubs	Herbs and forbs
Athrotaxis cupressoides	*Archeria* spp.	*Celmisia saxifraga*
Athrotaxis selaginoides	*Bauera rubioides*	*Plantago gunnii*
Eucalyptus coccifera	*Cyathodes petiolaris*	
Eucalyptus subcrenulata	*Diselma archeri*	
	Dracophyllum minimum	
	Microstrobos niphophilus	
	Olearia pinifolia	
	Ozothamnus rodwayi var. *rodwayi*	
	Phyllachne colensoi	
	Richea pandanifolia	

are known to be common elsewhere on dolerite mountains of Central Tasmania. The only native Tasmanian conifer present, *Podocarpus lawrencei*, has a highly localised distribution on the plateaux, suggesting that the areas have been subjected to extreme drought conditions in the past. The small perennial herb *Plantago gunnii* is absent from *Abrotanella forsteroides* cushions in the Northeast even though extensive potential habitat is present. The absence of these species may reflect their absence before the ice ages, or at least suggest they have always had a much contracted distribution. Cold arid periods may have been more extreme in the Northeast than in alpine and subalpine areas further west where precipitation may have been more reliable.

Ben Lomond and Mt Barrow are also both relatively free of introduced plants, except for areas associated with skiing development and road construction. *Eucalyptus coccifera*, a Tasmanian endemic, has been introduced near one ski lodge at Ben Lomond. Flatweed (*Hypochoeris radicata*) is a common weed. *Salix cinerea* may be more of a problem in the future; one large well-established shrub was found in alpine vegetation on Mt Barrow. *S. cinerea* has the potential to disperse downslope along watercourses, and requires a directed eradication effort. Thistle seeds from the Midlands can be seen blowing over the plateaux with the prevailing westerly winds, yet surprisingly few problems exist with establishment of thistles and other wind-dispersed weeds on either Ben Lomond or Mt Barrow.

Comparison of Ben Lomond and Mt Barrow with the Victorian alps

The following comments are based on the author's observations in the Victorian alps over the last 6 years on the Baw Baw plateau and Mt Hotham and in the Falls Creek areas. The alpine vegetation of Ben Lomond and

Table 2. Taxa with national southern limit of range on the Baw Baw plateau.

Trees and Shrubs	Herbs and Forbs
Asterolasia trymalioides	*Carex jackiana*
Baeckaea utilis var. *latifolia*	*Astelia alpina* var. *novae-hollandiae*
Callistemon pityoides	*Brachyscome obovata*
Epacris coriacea	*Caltha introloba*
Epacris paludosa	*Carex canescens*
Eucalyptus glaucescens	*Carpha nivicola*
Leucopogon fraseri	*Euphrasia gibbsaei* ssp. *glabrifolia*
Leucopogon gelidus	*Hydrocotyle algida*
Leucopogon maccraei	*Plantago alpestre*
Monotoca oreophila	*Plantago euryphylla*
Olearia megalophylla	
Olearia phlogopappa var. *flavescens*	
Orites lancifolia	
Oxylobium alpestre	
Pimelea alpina	
Richea continentis	
Richea victoriana	
Tasmannia vickeriana	
Trochocarpa clarkei	
Wittsteinia vacciniacea	

Mt Barrow tends to have a greater extent of shrubbiness, rockiness, periglacial rockfields, bedrock exposure, bogs, peat soils, and waterbodies such as tarns and lakes. It also tends to have a greater rock and stone component of soils, particularly at the surface, and a higher fire frequency, perhaps due to higher combustibility of shrub species. Members of the family Epacridaceae have a higher representation and abundance in Tasmania, whilst the families Mimosaceae and Fabaceae are more poorly represented compared to the Victorian alps. Finally the two biogeographic areas tend to be floristically distinct because of the presence of endemic mainland Australian alps and Tasmanian Northeast endemic species. The Australian alps species tend to have their national southern limit of range on the Baw Baw plateau (Davies 1994); these species are listed in Table 2. The endemic Tasmanian species are listed in Appendix 1.

Concluding remarks

The following topics require further research:

- Taxonomic and monitoring studies of *Chionohebe ciliolata* should be undertaken as the species has the potential to be a threatened Tasmanian endemic if future studies show it to be a new species. The species is extremely localised and die-back of cushions is evident.
- A vegetation survey should be conducted across the lower-altitude (montane) areas of Ben Lomond National Park which were not covered by the 1989 alpine/subalpine survey.
- The planted *Eucalyptus coccifera* seedlings at the ski village (altitude 1 445m) need to be monitored. Although they provide an interesting planting for scientific study, the population needs to be controlled to prevent any colonisation by seedlings.
- A taxonomic study should be undertaken to clarify the status of the hairy-leafed form of *Spyridium ulicinum* collected from the alpine area of State Forest on the Mt Barrow plateau.

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Appendix 1. List of vascular plants of Ben Lomond plateau and Mt Barrow State Reserve (see Davies & Davies 1989, 1990) for study area boundaries.

e = Tasmanian endemic
i = introduced
t = international disjunct distribution

		Ben Lomond	Mt Barrow
DICOTYLEDONAE			
APIACEAE			
	Hydrocotyle hirta R.Br. ex A.Rich.		✓
	Hydrocotyle sibthorpioides Lamk.	✓	✓
	Oreomyrrhis ciliata Hook.f.	✓	✓
e	*Oreomyrrhis sessiliflora* Hook.f.	✓	
ASTERACEAE			
e	*Abrotanella forsteroides* (Hook.f.) Benth.	✓	
e	*Bedfordia linearis* (Labill.) DC.		✓
e	*Bedfordia salicina* (Labill.) DC.		✓
e	*Brachyscome spathulata* Gaud.		
	ssp. *glabra* (DC.) Stace	✓	✓
	Brachyscome tenuiscarpa Hook.f.	✓	✓
	Cassinia aculeata (Labill.) R.Br.		✓
	Celmisia asteliifolia Hook.f.	✓	✓
	Cotula alpina (Hook.f.) Hook.f.		✓
	Craspedia alpina Backh. ex Hook.f.	✓	
	Erigeron pappocromus Labill.	✓	✓
	Euchiton argentifolius (Wakef.) A.Anderb.	✓	✓
	Euchiton traversii (Hook.f.) A.Anderb.	✓	
	Euchiton unbricola (J.H.Willis) A.Anderb.		✓
e	*Ewartia catipes* (DC.) P.Beauv.	✓	✓
e	*Ewartia planchonii* (Hook.f.) P.Beauv.	✓	✓
	Helichrysum scorpioides Labill.	✓	✓
i	*Hypochoeris radicata* L.	✓	
	Logenifera stipitata (Labill.) Druce	✓	✓
	Leptinella filicula (Hook.f.)Hook.f.	✓	✓
	Leontodon taraxacoides (Vill.) Mérat		✓
	Leptorhynchos squamatus (Labill.) Less.	✓	✓
	Microseris lanceolata (Walp.) Schultz-bip	✓	
	Olearia algida Wakef.	✓	
	Olearia argophylla (Labill.) Benth.		✓
e	*Olearia ledifolia* (DC.) Benth	✓	✓
	Olearia lirata (Sims) Hutch.		✓
e	*Olearia obcordata* (Hook.f.) Benth.	✓	✓
	Olearia phlogopappa (Labill.) DC.	✓	✓
e	*Olearia tasmanica* (Hook.f.) W.M.Curtis	✓	✓
	Olearia viscosa (Labill.) Benth.		✓
e	*Ozothamnus antennaria* (DC.) Hook.f.		✓
	Ozothamnus hookeri Sonder, Linnaea	✓	✓
e	*Ozothamnus rodwayi* Orch.		
	var. *kingii* (W.M.Curtis) P.S.Short	✓	✓
e	*Pterygopappus lawrencei* Hook.f.	✓	
	Senecio gunnii (Hook.f.) Belcher	✓	✓
i	*Senecio jacobaea* L.	✓	
	Senecio lautus Forst.f. ex Willd.	✓	✓
	Senecio pectinatus DC. var. *pectinatus*	✓	✓
BRASSICACEAE (CRUCIFERAE)			
	Cardamine gunnii Hewson	✓	✓
CAMPANULACEAE			
e	*Wahlenbergia saxicola* A.DC.	✓	✓
	Wahlenbergia sp.		✓
CARYOPHYLLACEAE			
e	*Colobanthus curtisiae* J.West	✓	
i	*Sagina apetala* Ard.		✓
	Scleranthus biflorus (Forst. & Forst.f.) Hook.f.	✓	
	Stellaria pungens Brongn.		✓
CLUSIACEAE (GUTTIFERAE, HYPERICACEAE)			
	Hypericum japonicum Thunb.	✓	

	Ben Lomond	Mt Barrow
CRASSULACEAE		
Crassula sieberana (Schultes & Schultes f.) Druce		✓
DROSERACEAE		
Drosera arcturi Hook.	✓	✓
Drosera peltata Thunb.		
subsp. *auriculata* (Backh. ex Planchon.)		✓
ELAEOCARPACEAE		
e *Aristotelia peduncularis* (Labill.) Hook.f.		✓
EPACRIDACEAE		
e *Cyathodes dealbata* R.Br.	✓	✓
e *Cyathodes glauca* Labill.		✓
e *Cyathodes parvifolia* R.Br.	✓	✓
e *Cyathodes straminea* R.Br.	✓	
Epacris gunnii Hook.f.	✓	✓
Epacris lanuginosa Labill.		✓
e *Epacris serpyllifolia* R.Br.	✓	✓
Leucopogon montanus (R.Br.) J.H.Willis	✓	
e *Monotoca empetrifolia* R.Br.	✓	✓
Pentachondra pumila (Forst. & Forst.f.) R.Br.	✓	✓
e *Richea acerosa* (Lindley) F.Muell.	✓	✓
e *Richea gunnii* Hook.f.	✓	✓
e *Richea scoparia* Hook.f.	✓	✓
e *Richea sprengelioides* (R.Br.) F.Muell.	✓	✓
Sprengelia montana R.Br.	✓	
e *Trochacarpa thymifolia* (R.Br.) Sprengel	✓	
ERICACEAE		
t *Gaultheria depressa* Hook.f.	✓	
e *Gaultheria hispida* R.Br.		✓
e *Gaultheria tasmanica* (Hook.f.) Middleton	✓	✓
ESCALLONIACEAE		
e *Tetracarpaea tasmanica* Hook.f.		✓
EUPHORBIACEAE		
Poranthera microphylla Brongn	✓	✓
FABACEAE (LEGUMINOSAE)		
Almaleea subumbellata (Hook.) Crisp & P.Weston	✓	✓
Oxylobium ellipticum (Labill.) R.Br.	✓	✓
Pultenaea juniperina Labill.	✓	✓
i *Trifolium* sp.	✓	
FAGACEAE		
Nothofagus cunninghamii (Hook.) Oersted		✓
GENTIANACEAE		
Gentianella diemensis (Griseb.) J.H.Willis	✓	✓
GERANIACEAE		
Geranium potentilloides L'Hérit. ex DC.	✓	✓
Geranium sessiliflorum Cav.		✓
Pelargonium australe Willd.	✓	
GOODENIACEAE		
Scaevola hookeri (Vriese) F.Muell. ex Hook.f.	✓	✓
Velleia montana Hook.f.	✓	✓
HALORAGACEAE		
Gonocarpus montanus (Hook.f.) Orch.	✓	✓
Gonocarpus serpyllifolius Hook.f.	✓	
Myriophyllum pedunculatum Hook.f.		
var. *pedunculatum*	✓	✓
LAMIACEAE (LABIATAE)		
Prostanthera lasianthas Labill.		✓
e *Westringia rubiaefolia* R.Br.	✓	✓
LOGANIACEAE		
Mitrasacme serpyllifolia R.Br.	✓	

	Ben Lomond	Mt Barrow
MIMOSACEAE		
e *Acacia axillaris* Benth.		✓
Acacia dealbata Link.		✓
MONIMIACEAE		
Atherosperma moschatum Labill.		✓
MYRTACEAE		
Baeckea gunniana Schauer	✓	✓
e *Callistemon viridiflorus* (Sims) Sweet		✓
e *Eucalyptus archeri* Maiden & Blakely	✓	✓
e *Eucalyptus delegatensis* R.Baker		
subsp. *tasmaniensis* Boland		✓
e *Eucalyptus coccifera* Hook.f. [NB planted specimens only]	✓	
e *Eucalyptus gunnii* Hook.f.		✓
Leptospermum lanigerum (Aiton) Smith	✓	✓
e *Leptospermum rupestre* Hook.f.	✓	✓
OLEACEAE		
Notelaea ligustrina Vent.		✓
ONAGRACEAE		
Epilobium curtisiae Raven	✓	
e *Epilobium fugitivum* Raven & Engelhorn	✓	
Epilobium sarmentaceum Hausskn., Oesterr	✓	✓
Epilobium tasmanicum Hausskn.	✓	
Epilobium willisii Raven & Engelhorn	✓	
OXALIDACEAE		
i *Oxalis corniculata* L.		✓
PITTOSPORACEAE		
Billardiera longiflora Labill. var. *longiflora*	✓	✓
Pittosporum bicolor Hook.	✓	✓
PLANTAGINACEAE		
e *Plantago daltonii* Decne.	✓	
e *Plantago paradoxa* Hook.f.	✓	
e *Plantago tasmanica* Hook.f. var. *tasmanica*	✓	✓
POLYGONACEAE		
i *Acetosella vulgaris* Fourr.	✓	✓
PORTULACACEAE		
Neopaxia australasica (Hook.f.) Ö. Nilss.	✓	
PROTEACEAE		
e *Bellendena montana* R.Br.	✓	✓
Grevillea australis R.Br.	✓	✓
Hakea lissosperma R.Br.	✓	✓
e *Lomatia tinctoria* (Labill.) R.Br.		✓
e *Orites acicularis* (R.Br.) Roemer & Schultes	✓	✓
e *Orites revoluta* R.Br.	✓	✓
e *Persoonia gunnii* Hook.f., Hook. var. *gunnii*	✓	
e *Persoonia muelleri* (P.Parm.) Orch.		✓
e *Telopea truncata* (Labill.) R.Br.		✓
RANUNCULACEAE		
Clematis aristata R.Br. ex DC.		✓
Ranunculus gunnianus Hook.	✓	✓
Ranunculus lappaceus Smith		✓
e *Ranunculus nanus* Hook.	✓	
e *Ranunculus triplodontus* Melville	✓	
RHAMNACEAE		
e *Cryptandra alpina* Hook.f.	✓	✓
Pomaderris apetala Labill.		✓
ROSACEAE		
e *Acaena montana* Hook.f.	✓	
Acaena novae-zelandiae Kirk	✓	✓
e *Rubus gunnianus* Hook.	✓	✓

	Ben Lomond	Mt Barrow
RUBIACEAE		
Asperula gunnii Hook.f., Hook.	✓	
Asperula pusilla Hook.f., Hook		✓
Coprosma hirtella Labill.		✓
Coprosma nitida Hook.f. Hook.	✓	✓
Coprosma perpusilla Colenso		✓
Coprosma pumila Hook.f.	✓	
Coprosma quadrifida (Labill.) Robinson		✓
Galium australe DC.	✓	✓
Galium ciliare Hook.f.	✓	
RUTACEAE		
Boronia citriodora Gunn ex Hook.f.	✓	✓
Correa lawrenciana Hook. var. *lawrenciana*		✓
e *Phebalium montanum* Hook.	✓	✓
e *Phebalium squameum* (Labill.) Engl. subsp. *retusum* (Hook.)		✓
SALICACEAE		
i *Salix cinerea* L.		✓
i *Populus* sp.		✓
SANTALACEAE		
e *Exocarpos humifusus* R.Br.	✓	✓
SCROPHULARIACEAE		
t *Chionohebe ciliolata* (Hook.f.) B.Briggs & Ehrend.	✓	
e *Euphrasia collina* R.Br. subsp. *diemenica* (Sprengel) W.R.Barker	✓	✓
Gratiola nana Benth.	✓	
e *Ourisia integrifolia* R.Br.	✓	✓
i *Verbascum virgatum* Stokes		✓
Veronica calycina R.Br.	✓	✓
STACKHOUSIACEAE		
Stackhousia monogyna Labill.	✓	
STYLIDIACEAE		
Stylidium graminifolium Swartz	✓	✓
THYMELAEACEAE		
Kelleria dieffenbachii (Hook.) Endl.	✓	
Pimelea drupacea Labill.		✓
Pimelea ligustrina Labill. subsp. *ligustrina*		✓
e *Pimelea sericea* R.Br.	✓	✓
TREMANDRACEAE		
e *Tetratheca procumbens* Gunn ex Hook.f.	✓	✓
URTICACEAE		
Australina pusilla (Desf. ex Poiret) Gaudich.		✓
Urtica incisa Poiret		✓
VIOLACEAE		
Hymenanthera dentata R.Br. ex DC.	✓	
Viola betonicifolia Smith	✓	
Viola hederacea Labill.	✓	✓
WINTERACEAE		
Tasmannia lanceolata (Poiret) A.C.Smith	✓	✓
MONOCOTYLEDONAE		
CENTROLEPIDACEAE		
e *Centrolepis muscoides* (Hook.f.) Hieron.	✓	
CYPERACEAE		
Carex archeri Boott in Hook.f.	✓	
Carex breviculmis R.Br.	✓	
Carex gaudichaudiana Kunth	✓	✓
Carex aff. *diandra* Schrank	✓	
Carex raleighii Nelmes		✓
Carpha alpina R.Br.	✓	✓

	Ben Lomond	Mt Barrow
Gahnia grandis (Labill.) S.T.Blake		✓
Isolepis crassiuscula Hook.f.	✓	✓
Isalepis subtilissima Boeck.	✓	✓
Lepidasperma filiforme Labill.		✓
Oreobolus distichus F.Muell.	✓	✓
Oreobolus pumilio R.Br.	✓	✓
Schoenus calyptratus Kük.	✓	
Uncinia campacta R.Br.	✓	✓
Uncinia tenella R.Br.		✓
t *Uncinia nervosa* Boot	✓	

JUNCACEAE

Juncus sandwithii Lourteig	✓	✓
Luzula acutifolia Nordensk.	✓	
Luzula australasica Steudel	✓	
Luzula densiflora (Nordensk.) Edgar		✓
Luzula modesta Buchenau		✓
Luzula sp.		✓

LILIACEAE

e *Astelia alpina* R.Br. var *alpina*	✓	✓
Drymophila cyanocarpa R.Br.		✓

ORCHIDACEAE

Chilaglottis cornuta Hook.f.		✓
Caladenia alpina Rogers	✓	
e *Prasophyllum alpinum* R.Br.	✓	✓
Prasophyllum suttonii R.Rogers & B.Rees	✓	

POACEAE (GRAMINEAE)

i *Agrostis capillaris* L.		✓
Agrostis parviflora R.Br.	✓	
Agrostis sp.		✓
Agrostis venusta Trin.	✓	
i *Anthoxanthum odoratum* L.	✓	
e *Australopyrum pectinatum* (Labill.) A.Löve		✓
e *Danthonia diemenica* D.I.Morris	✓	✓
Danthonia nivicola Vick.	✓	
Danthonia nudiflora P.Morris	✓	
e *Danthonia pauciflora* R.Br.	✓	✓
Danthonia penicillata (Labill.) R.Br.		✓
Deschampsia cespitosa (L.) P.Beauv.	✓	✓
Deyeuxia carinata Vick.	✓	✓
Deyeuxia monticola (Roemer & Schultes) Vick.	✓	✓
e *Ehrharta tasmanica* (Hook.f.) Willemse		✓
e *Hierochloe fraseri* Hook.f.	✓	✓
Hierochlae redolens (Vahl) Roemer & Schultes	✓	
Poa costiniana Vick.	✓	✓
Poa fawcettiae Vick.	✓	✓
e *Poa gunnii* Vick.	✓	✓
Poa hiemata Vick.	✓	
Poa labillardierei Steudel	✓	✓
Poa sieberiana Sprengel		✓
Trisetum spicatum (L.) Richter	✓	✓
i *Vulpia bromoides* (L.) Gray		✓

RESTIONACEAE

Empodisma minus (Hook.f.) L.Johnson & Cutler	✓	✓
Restia australis R.Br.	✓	✓

GYMNOSPERMAE

PINACEAE

i *Pseudotsuga menziesii* (Mirb) Franco		✓

PODOCARPACEAE

Podocarpus lawrencei Hook.f.	✓	

TAXODIACEAE

i *Sequoia sempervirens* (D. Don) Endlicher		✓
i *Sequoiadendron giganteum* (Lindl.) Buchh		✓

	Ben Lomond	Mt Barrow
PTERIDOPHYTA		
ASPLENIACEAE		
Asplenium bulbiferum Forst.f.		✓
BLECHNACEAE		
Blechnum fluviatile (R.Br.) E.J.Löwe ex Salomon		✓
Blechnum penna-marina (Poiret) Kuhn	✓	✓
Blechnum wattsii Tind.		✓
DENNSTAEDTIACEAE		
Histiopteris incisa (Thunb.) J.Smith		✓
Hypolepis rugosula (Labill.) J.Smith		✓
Pteridium esculentum (Forst.f.) Cockayne		✓
DICKSONIACEAE		
Dicksonia antarctica Labill		✓
DRYOPTERIDACEAE		
Polystichum proliferum (R.Br.) C.Presl	✓	✓
GLEICHENIACEAE		
Gleichenia alpina R.Br.	✓	✓
Gleichenia microphylla R.Br.		✓
GRAMMITIDACEAE		
Grammitis poeppigiana (Mett.) Pichi-Serm	✓	✓
HYMENOPHYLLACEAE		
Hymenophyllum cupressiforme Labill.		✓
Hymenophyllum peltatum (Poiret) Desv.	✓	
ISOETACEAE		
e *Isoetes gunnii* A.Braun	✓	
LYCOPODIACEAE		
Huperzia australiana (Herter) Holub	✓	
Lycopodium fastigiatum R.Br.	✓	✓
Lycopodium scariosum Forst.f.	✓	✓

Lowland Forests and Woodlands in Northeast Tasmania

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Abstract

Lowland forests and woodlands occupy about 400 000 ha in northeast Tasmania. Their vascular flora has strong affinities with that of southeast Australian mainland forests. About 60 species categorised as rare or threatened in Tasmania occur in the Northeast lowland forests. The non-vascular flora is poorly known. Dry sclerophyll forests and woodlands (mainly dominated by *Eucalyptus amygdalina*, *E. obliqua* and *E. sieberi*) are widespread on relatively dry or infertile sites. Wet sclerophyll forests (mainly dominated by *E. obliqua* or *E. regnans*) occur on more humid, more fertile or less frequently burnt sites. Rainforest tree species (*Nothofagus cunninghamii*, *Atherosperma moschatum*) are only prominent on very humid, fire-shadow sites; emergent eucalypts are usually present, though callidendrous rainforest can develop if fire is excluded for a prolonged period. Blackwood (*Acacia melanoxylon*) forests occur locally in gullies and on broad flats. The lowland forests and woodlands have been affected by Aboriginal burning practices, and subsequently by European settlement, agriculture, forestry, mining, fire regimes and the introduction of exotic species. About 30 000 ha of lowland forests are in existing or proposed reserves, but off-reserve conservation management will be important in maintaining regional biodiversity.

Introduction

Native forests effectively surround the mountainous bulwarks of the Northeast - the Ben Lomond massif, Mt Victoria, Mt Maurice, Blue Tier and the other ranges and plateaux that give the region so much of its character and diversity, and influence (mainly through climate) the character and diversity of the forests themselves.

Lowland forests, and associated woodlands, are defined here as tree-dominated vegetation which occupies an altitudinal range from sea level to about 500 m. The latter elevation typically corresponds to the transition zone when forests dominated by *Eucalyptus obliqua* are replaced by forests dominated by *E. delegatensis*. Projected canopy cover is used to differentiate forests and woodlands: forests have a cover exceeding 30% while woodlands have a cover of 10-30%. To save repetition, the term 'forest' is used in a general sense for tree-dominated vegetation, except when a woodland structure is meant specifically. The Northeast, as defined in this paper, corresponds with Nature Conservation Regions 5 and 6 (Working Group for Forest Conservation 1990). Species nomenclature in this paper follows Buchanan (1995).

A rough estimate of 400 000 ha can be given for the current area of lowland forests in the Northeast. This is about 60% of their pre-European cover. However, it is not easy to quantify their extent, partly because of the problem of ascribing recently modified but predominantly native vegetation (e.g. silvicultural regeneration) to different vegetation types. In addition, the boundaries between lowland and upland forests are somewhat arbitrary. At low altitudes, the lowland forests run into coastal scrub, heath or the coast itself (in the north and east of the region), and into the broad, grassy plains and woodlands of the Tamar Valley, Midlands and

the Fingal Valley (in the west and south of the region).

Aboriginal land use influenced the structure and composition of forests and associated vegetation in the Northeast. Subsequently, the lowland forests have been differentially affected by European settlement. Those growing on arable, accessible or more fertile sites have been more extensively cleared for townships, agriculture or (more recently) plantations than their counterparts on steeper, more remote or less fertile country. Most of the remaining native forests have been affected by some form of economic activity. These mainly comprise grazing by stock (particularly in grassy forests and woodlands), mining (which has mainly affected forests on granite or prospective sediments) and logging (with wet eucalypt forests being favoured for production of sawlogs in the past, but with a substantial extension of intensive logging in both wet and dry forests in the last few decades). The effects may not be readily apparent, particularly in areas where such land use has been light, intermittent, or long-abandoned. Frequent burning, often associated with these activities, has also influenced the structure and composition of the vegetation. The biological value of many forested areas has been reduced, probably irreversibly, by the introduction of weeds and disease (notably the root rot pathogen *Phytophthora cinnamomi*).

Conservation of a range of forest types is recognised as a valid land use, important in maintaining biodiversity, as well as providing the many other benefits which accrue from preserving natural environments. About 30 000 ha of lowland forest occurs in existing reserves (e.g. Mt William National Park, St Columba Falls State Reserve) or reserves proposed on public land (Working Group for Forest Conservation 1990). More recent initiatives, notably the proposed Comprehensive Regional Assessment of Tasmanian forest types, should result in a more balanced conservation network, which will include

forest types which occur mainly on private land. Off-reserve management will also be important in conserving regional diversity in the Northeast.

There are some published descriptions of lowland forest vegetation in northeast Tasmania, though ecological processes in the upland forests have been documented more thoroughly (e.g. Ellis 1985, Ellis & Graley 1987). Stephens and Cane (1939) and Pinkard (1980) provide general descriptions of the vegetation of the Northeast, and its relationship with the environment. Remnant heaths, forests and woodlands occurring on the Great Northern Plain are described by Kirkpatrick and Wells (1987), and forest vegetation in the Spurrs Rivulet catchment has been analysed (Peters 1984). Neyland and Askey-Doran (this volume) attempt to develop a correlation between fire regimes and the composition and structure of *Eucalyptus sieberi* forests on granite and sediments. Moisture availability, drainage, edaphic factors and fire history had a major influence on composition and structure of granite-based forests in the catchment of the Great Musselroe River (Duncan & Brown 1995). Several areas of lowland forest have been surveyed as part of conservation and management planning in the Northeast. They include surveys of existing and proposed reserves, and areas proposed for development or resource extraction.

This paper draws on published material, unpublished sources and field observations to outline the flora and structure of the Northeast lowland forests, and to discuss the influence of major environmental variables on their distribution and characteristics. Conservation of lowland forests is also discussed, with attention being given to some of the species and communities of biogeographic or conservation significance.

Flora

The vascular flora of lowland forests in the Northeast is dominated by Australian elements of the flora. Antarctic (or Gondwanic) species are confined to humid, fire-shadow sites supporting rainforests dominated by *Nothofagus cunninghamii* (myrtle) or *Atherosperma moschatum* (sassafras), or eucalypt forests with rainforest understoreys (mixed forests).

The Northeast lowland forests have a relatively low proportion of Tasmanian endemic species, compared to the proportion in many other Tasmanian forest environments. This is largely because of the region's proximity and past connections to the Australian mainland and because the major geologies of the Northeast, with the exception of dolerite, are also common to the southeast Australian mainland. In addition, the strong or localised selection pressures which are associated with endemic-rich habitats elsewhere in Tasmania (e.g. drought-prone dolerite sites on the central East Coast, high-altitude environments on the Central Plateau, infertile quartzite sites in the Southwest; see

Kirkpatrick & Brown 1984) are notably absent from the Northeast lowlands. Kirkpatrick and Potts (1987) suggest that a vast treeless zone in the Last Glacial may have blocked the movement, into north Tasmania, of some species of eucalypts (e.g. *E. cordata*, *E. pulchella*, *E. tenuiramis*) which are largely restricted to the southeast of the State. Endemic-rich rainforest types are confined to the Central Highlands and Tasmania's west and south (Jarman et al. 1984).

Some Tasmanian endemic species (e.g. *E. amygdalina*, *Lomatia tinctoria*) are widespread in the Northeast lowland forests. Other species (e.g. *E. rodwayi*, *Callistemon viridiflorus*) have more localised distributions. Many of the endemic species (e.g. *Veronica formosa*, *Pimelea filiformis*, *Dodonaea filiformis*) are strongly associated with rocky dolerite sites. Some endemic species which occur in upland forests in the Northeast (e.g. *Phyllocladus aspleniifolius*, *Telopea truncata* and *Persoonia muelleri*) are absent from lowland forests.

There are several Northeast lowland forest species which have been categorised as rare, threatened or inadequately reserved in Tasmania, in recent reviews of the reservation and conservation status of Tasmania's vascular flora (Kirkpatrick et al. 1991, Flora Advisory Committee 1994). About 60 of these species have been listed in schedules of the Tasmanian Threatened Species Protection Act (1995), which specifies procedures to be followed if a proposed land use has the potential to affect critical habitats of listed species. The Commonwealth Endangered Species Protection Act (1992) lists five Northeast forest species as being vulnerable or endangered at a national level; the Commonwealth is required to avoid actions which could threaten a listed species.

Research has been conducted into the distribution, ecology and management of several rare or threatened forest species. They include *Pultenaea hibbertioides*, *Hovea corrickiae*, *Bossiaea obcordata* (Lynch 1993); *Hovea corrickiae*, *Hibbertia calycina* (Hopkins 1995); *Phebalium daviesii* (Lynch 1994); *Callitris oblonga* (Harris & Kirkpatrick 1991a,b) and *Blechnum cartilagineum* (Garrett 1992). The species with the highest priority for conservation is the endangered riverine shrub *Phebalium daviesii*; 23 individuals were recently discovered on the lower George River, after the species had eluded botanists (and grazing cattle) since it was last collected in this area in 1892 (Lynch 1994). Most lowland forest species of conservation significance occur in drier forests and woodlands; many are also of biogeographic significance, because in Tasmania they are largely or entirely restricted to the Northeast.

Sixteen rare or threatened forest species occurring in the Northeast lowlands were tested for their susceptibility to *Phytophthora cinnamomi*; only one species (*Prostanthera rotundifolia*) was resistant to the pathogen (Barker 1994).

Several areas have been zoned for protective management (mainly on a catchment basis) to reduce the risk of *Phytophthora* being introduced to important populations of susceptible species (Barker 1994).

There is little information on the non-vascular flora of Northeast lowland forests, with only limited sampling having occurred in the region. General trends described from other areas of Tasmania (e.g. Ratkowsky & Ratkowsky 1982; Kantvilas et al. 1985; Ratkowsky et al. 1989; Jarman & Fuhrer 1995) can be extrapolated to the Northeast. The abundance and diversity of bryophytes (mosses and liverworts) is greatest in rainforest, becoming progressively less as the forest environment becomes drier and more open. Rainforests, particularly those dominated by old-growth trees, support the richest lichen flora, with a wide range of substrates being available compared to regrowth forests and drier forest types. However, no visitor could be oblivious to the colours and forms of the lichens which grow on living and dead trees and shrubs, and the rocks and boulders, in many of the Northeast's drier lowland forests. Research on the non-vascular flora of the Northeast forests has a high priority, because of the paucity of existing information and the probable occurrence of species which are uncommon or undescribed (G. Kantvilas, pers. comm.).

Forest types and communities

This section gives a generalised overview of the characteristics, distribution and habitats of the main lowland forest types occurring in the Northeast. Rainforest, mixed forest and blackwood forests are very localised, the two former types being more common in upland areas. Wet sclerophyll forests are more widespread, but in many lowland areas are confined to sites with relatively high moisture availability. Dry sclerophyll forests and woodlands are the most extensive vegetation type in lowland areas of the Northeast, and are the most variable in their structure and composition. The final section of this paper gives a more detailed treatment of granite-based forests and associated communities in the Great Musselroe River catchment, indicating the role of fire, landform and edaphic factors in influencing the structure and composition of vegetation at a local level. The situation in this area is representative of processes occurring in many lowland forest environments in the Northeast.

The recent assessment of the reservation status of plant communities occurring in Tasmania (Kirkpatrick et al. 1995), and information from field surveys and other sources, indicates that most of the forest communities are well reserved at a regional or statewide level, or occur in proposed reserves. However, except for some comments on localised communities, I have not discussed conservation of different forest types in this section, partly because of the confusion currently surrounding the forest conservation picture, pending completion of the

Comprehensive Regional Assessment.

Rainforest

Rainforest occurs as relict patches, mainly less than 20 ha in area, which are restricted to humid gullies and slopes in the middle and upper reaches of major streams (e.g. Great Musselroe River, Great Forester River, Wyniford River). The landform and microclimate, and the mesomorphic (soft-leaved) nature of the vegetation, means that rainforest is burnt less frequently (generally at intervals of over 100 years), than surrounding eucalypt forests. Neyland (1991) identifies two facies of rainforest in the Northeast lowlands. These are callidendrous sassafras - musk rainforest (dominated by *Atherosperma moschatum*) and callidendrous myrtle rainforest (dominated by *Nothofagus cunninghamii*). The term 'callidendrous' means beautiful trees, and refers to the size and shape of the dominants. The understorey is open and park-like compared to the tangled understoreys of the endemic rainforest communities of southwest Tasmania. Although small trees and shrubs are present (e.g. *Olearia argophylla*, *Coprosma quadrifida* and regeneration of the dominant tree species), it is the diversity and cool luxuriance of manferns (*Dicksonia antarctica*), ground ferns (e.g. *Polystichum proliferum*, *Blechnum wattsii*), epiphytic ferns and bryophytes which draw the eye, and the body, on a hot summer's day. Callidendrous rainforest of similar structure and composition occurs more extensively in upland areas of the Northeast.

Most lowland rainforest is in State forest and has been zoned for reservation or other conservation management. Boundaries of the rainforest patches are relatively stable, and exclusion of forestry-related disturbance from buffer zones around rainforest patches should ensure their survival in the absence of major wildfires or climatic upheavals (Neyland 1991). Patches dominated by myrtle are at greater risk from disturbance than those dominated by sassafras, because of the greater susceptibility of the former species to fire and mechanical damage, which can lead to infection by the myrtle wilt fungus, *Chalara australis* (Packham 1991). The plumose achenes of sassafras also allow their seeds to be dispersed over longer distances than the seeds of myrtle.

Blackwood forest

Forests dominated by *Acacia melanoxylon* (blackwood) occur locally on river flats and in gullies in the Northeast lowlands. The understorey is mesomorphic and contains many species which also occur in rainforest. Massive germination of soil-stored blackwood seed results if sites are disturbed by fire, floods or mechanical disturbance (e.g. logging). Jennings (1991) reports field germination of 38 500 seedlings per hectare following logging and burning in swamp forests in northwest Tasmania, and 70 000 seedlings per hectare in eucalypt-blackwood forests.

Two of the blackwood forest communities identified by Pannell (1992) have been recorded from the Northeast. Callidendrous swamp forest occurs on a broad, poorly drained flat on the Great Forester River and smaller remnants are found on other river flats. The community is dominated by *A. melanoxylon* and *Leptospermum lanigerum*, and has a depauperate understorey which includes *Atherosperma moschatum*, *Dicksonia antarctica*, *Coprosma quadrifida*, *Lepidosperma elatius*, *Gahnia sieberiana* and *Blechnum* spp. Callidendrous swamp forests are more widespread in the lowland swamps of northwest Tasmania, and remnant occurrences in the Northeast, particularly the large stand on the Great Forester River, have a high priority for conservation management. The second blackwood community, riparian blackwood forest, is dominated by *A. melanoxylon* with *A. dealbata* (silver wattle) occasionally present. The understorey is similar to that of callidendrous rainforest. This community is more widespread than callidendrous swamp forest, but is typically localised in well-drained gullies surrounded by eucalypt forest.

Mixed forest

Mixed forest has an understorey of rainforest species and an overstorey of eucalypts; the latter are generally of a single age class and become sparse as the forest approaches maturity. *Eucalyptus regnans* and *E. obliqua* are the main mixed forest dominants in the Northeast, though localised patches of *E. viminalis* mixed forest are associated with streams. These include Evercreech Creek where the Northeast's tallest trees, reaching a height of 90 m, are located. The rainforest understorey has a callidendrous structure and composition, as described above. Most of the lowland mixed forest in the Northeast can be ascribed to communities described by Kirkpatrick et al. (1988b).

Lowland mixed forest occurs on humid, fire-shadow sites, often in association with more successionally advanced rainforest. Research in similar environments elsewhere in Tasmania indicates that mixed forest is maintained by infrequent wildfire (at intervals of about 100 to 300 years) or other severe disturbance (including intensive logging), which removes the dense shrub/small tree canopy and permits the establishment of shade-intolerant eucalypt seedlings. If disturbance is too infrequent, pure rainforest develops as the venerable eucalypts become moribund and die. If fire or disturbance are too frequent, the rainforest elements can be lost from the understorey, and wet sclerophyll forest is likely to prevail at the site. Regeneration and succession following fire and logging in Tasmanian lowland mixed forests have been described for vascular species (e.g. Gilbert 1959, Hickey 1994) and non-vascular species (e.g. Duncan & Dalton 1982, Kantvilas et al. 1985).

Wet sclerophyll forest

Wet sclerophyll forests have a tall dominant stratum of eucalypts and an understorey dominated by mesomorphic shrubs. The understorey tends to be single-layered and dense, precluding regeneration of shade-intolerant species, including eucalypts, in the absence of major disturbance. Fire frequency varies from between 20 and 100 years (Jackson 1968, Mount 1979). Eucalypt trees can survive occasional fires, hence more than one eucalypt age class may be present in some stands, particularly in drier environments. Succession to mixed forest can occur if fire or disturbance are excluded and a source of myrtle or sassafras seed is available. However, occupation of drier habitats (relative to mixed forests) and the ability of eucalypts to produce flammable litter, augmented in many areas by intensive logging, tend to maintain a level of fire or disturbance which perpetuates wet sclerophyll forest.

Eucalyptus obliqua is the most widespread dominant of lowland wet sclerophyll forest in the Northeast, occurring on a range of substrates and landforms. The other main dominants are *E. regnans* (fertile sites), *E. viminalis* (riverine environments and flats), *E. brookeriana* and *E. globulus* (gullies and drainage lines in the St Marys area) and *E. sieberi* (gullies and fire-shadow sites on Mathinna sediments and granite). Characteristics of the understorey are strongly related to site characteristics, including geology, landform and fire or disturbance history. In the Northeast, more widespread wet sclerophyll understorey species include *Acacia dealbata*, *A. melanoxylon* (secondary trees); *Olearia argophylla*, *Pomaderris apetala*, *Acacia verniciflua*, *A. verticillata*, *Coprosma quadrifida*, *Cassinia trinerva*, *C. aculeata*, *Zieria arborescens* (shrubs); *Dicksonia antarctica*, *Polystichum proliferum*, *Pteridium esculentum*, *Culcita dubia*, *Blechnum* spp. (ferns) and *Gahnia sieberiana* and *Lepidosperma* spp. (graminoids). Lowland wet sclerophyll forest communities occurring in the Northeast are described by Kirkpatrick et al. (1988b).

Dry sclerophyll forest and woodland

Tasmanian dry sclerophyll vegetation is typically dominated by eucalypts and has a multi-layered understorey dominated by scleromorphic (hard-leaved) shrubs. Composition of the ground layer is variable; *Pteridium esculentum* (bracken), graminoids or grasses are the most common components. Eucalypt-dominated forests generally have a mixed species, multi-aged overstorey. Most trees survive fire through epicormic sprouting, but fire can facilitate regeneration by improving opportunities for germination and successful establishment, and by releasing seedlings or saplings from suppression. Several facies of lowland dry sclerophyll vegetation occur in the Northeast. They are described below after Duncan and Brown (1985), and Kirkpatrick et al. (1988a) for grassy forests and woodlands.

Heathy forests have an understorey dominated by shrubs less than two metres in height, and a ground layer which

usually contains bracken. Heathy forests are widespread in coastal and hinterland areas, where they are associated with siliceous substrates. *Eucalyptus amygdalina* dominates heathy forests throughout much of its range, co-occurring with *E. obliqua* on many sites as moisture availability or fertility increases (see following section). *Eucalyptus sieberi* dominates some areas of granite-based heathy forests in the St Helens - Scamander area. *Eucalyptus viminalis* is generally present as a minor species, but assumes dominance on coastal sands in some areas (e.g. at Waterhouse, where its low height at maturity contrasts markedly with the tall trees of the same species at Evercreech Creek). Agricultural clearing on the Great Northern Plain has spared only a few vestiges of *E. pauciflora*-dominated heathy forests, and it is this community which has one of the highest priorities for conservation in the Northeast. The main understorey species in heathy forests include *Allocasuarina littoralis* (bull-oak, which forms locally dense copses), *A. monilifera*, *Banksia marginata*, *Xanthorrhoea australis*, *Acacia* spp., *Aotus ericoides*, *Kunzea ambigua*, *Leptospermum scoparium*, *Epacris impressa*, *Leucopogon* spp., *Pimelea linifolia*, *Dillwynia* spp., *Hibbertia* spp. and *Amperea xiphoclada* (small trees and shrubs) and *Pteridium esculentum* and *Lepidosperma concavum* (ground layer species). Orchids are widespread in heathy forests in the Northeast; they include *Dendrobium striolatum*, Tasmania's only lithophytic orchid species, as well as a great diversity of terrestrial species. In many areas of the Northeast, a high frequency of prescribed (and unprescribed) burning has favoured the proliferation of bracken at the expense of shrub species which regenerate from seeds or rootstocks and have their regenerative resources exhausted by successive fires (Purdie 1977a,b; Gill 1981). Records of European seafarers, surveyors and the Aboriginal Conciliator, G.A. Robinson, indicate that such burning practices may emulate Aboriginal fire regimes. In 1831, Robinson noted of the Mt Horror area that '...*the country through which I travelled today is low and heathy, with undulating hills and open forest...The whole of the country had been burnt off by the natives and is a favourite hunting ground for them*...' (Plomley 1966, p. 383).

Forests and woodlands with scrubby understoreys dominated by *Leptospermum* spp. (tea-trees) or *Melaleuca* spp. (paperbarks), or with understoreys dominated by sedges and other graminoids (sedgey forests and woodlands), occur locally on poorly drained flats and soaks on most substrates, but previously achieved their greatest extent on the broad flats and plains of the north coast and hinterland. These communities have been cleared and drained throughout much of their range in the Northeast. *Eucalyptus ovata* dominates most remnants but this species is replaced by *E. rodwayi* on some lowland marshes (e.g. Rattrays Marsh). *Eucalyptus amygdalina* dominates some flats and marsh edges where drainage is not too impeded. The fire regime and drainage characteristics of the site influences the relative abundance of either shrubs or graminoids (e.g.

Gymnoschoenus sphaerocephalus, *Restio* spp., *Gahnia sieberiana*, *Lepidosperma* spp., *Juncus* spp.). Higher fire frequencies favour graminoids because of their capacity for rapid vegetative recolonisation. Many of the understorey species are intolerant of low light levels and are eliminated or much reduced in cover or abundance (with consequent reduction in species diversity) by canopy closure if the interval between fires increases substantially (Duncan & Brown 1995).

Argillaceous sediments, including the fine-grained Ordovician sediments known as the Mathinna Beds, generally support forests with a shrubby understorey. These forests are mainly dominated by *E. amygdalina* and *E. obliqua* in the north of the region, and have a relatively dense understorey containing both scleromorphic and mesomorphic shrubs. However, on the dry, dissected hills in the east of the region, *E. sieberi* forms monotypic stands. Their varnished leaves and shining branches contrast with dark, fissured trunks, made more prominent by the sparse understorey. The few woody species growing on the thin soils include *Allocasuarina littoralis*, *Pultenaea gunnii* and *Tetratheca labillardierei*, and (less commonly) some species considered to be rare or vulnerable in Tasmania (*Hibbertia calycina*, *Hovea corrickiae*, *Bossiaea obcordata*). Neyland and Askey-Doran (this volume) suggest that repeated fuel reduction burning, at intervals of about seven years, may be responsible for the low species diversities (and the prevalence of vegetative reproducers) in the *E. sieberi* forests of the Northeast, compared to *E. sieberi* forests occupying comparable but less frequently burnt sites in Victoria. However, long-unburnt *E. sieberi* forests in the Northeast can be just as depauperate as forests which are subjected to frequent burning, and it may be that firing by Aborigines had already eliminated many species from these forests. The surveyor J.H. Wedge, travelling from Falmouth to Scamander then west to the head of Georges Bay in December 1825, wrote that '...*the whole distance, with the exception of the short distance on the sea shore, was a succession of very steep, rocky and barren Hills - not a tuft of grass the whole way excepting at the first small bay that we made*' (Crawford et al. 1962, p. 23). In January 1830, Wedge wrote of arriving at the head of a small bay on the south side of the George River after '...*a long and hard days walk. Steep Ridgy Hills, destitute of herbage thickly timbered - but free from underwood from the above-mentioned cause* [*having been burnt by the natives*]' (Crawford et al. 1962, p. 59).

Lowland forests and woodlands on dolerite or dolerite-derived alluvium are largely restricted to the west and southwest parts of the Northeast. On relatively humid sites, *E. obliqua* dominates shrubby forests, often with mesomorphic as well as scleromorphic species in their understorey. However, most of the dolerite country formerly supported grassy forests and woodlands, which are now represented in many areas by remnant stands and paddock trees. The grassy forests and woodlands are typically dominated by *E. amygdalina*, *E. viminalis* and

Fig. 1. Mills Plains, painted c. 1832-1834 by John Glover. Reproduced with the permission of the Tasmanian Museum and Art Gallery.

occasionally *E. rubida*, *E. pauciflora* and *E. ovata*. They have relatively open strata of small trees and taller shrubs, including *Acacia mearnsii*, *A. dealbata*, *Bursaria spinosa* and *Allocasuarina verticillata* (she-oak), which forms locally dense stands on dry, rocky sites. The dense ground layer is dominated by native grasses (e.g. *Themeda triandra*, *Poa* spp., *Danthonia* spp., *Ehrharta stipoides*, *Dichelachne rara*) with a diverse array of prostrate shrubs (e.g. *Lissanthe strigosa*, *Astroloma humifusum*, *Bossiaea prostrata*), graminoids (e.g. *Lomandra longifolia*, *Lepidosperma* spp., *Diplarrena moraea*) and forbs (e.g. *Viola hederacea*, *Dichondra repens*) also present. The 'fire-stick farming' practices of the aborigines (Jones 1969, Kirkpatrick et al. 1988a, Duncan 1990), undertaken to promote green-pick (to attract game) and prevent tussock-forming grasses from crowding out species of inter-tussock herbs (which also formed part of the Aborigines' larder), helped to maintain a woodland rather than forest structure. Replacement of eucalypts would have occurred, but 'infilling' would have been discouraged by high seedling mortality resulting from fire, frost, predation, drought and competition. John Glover's evocative painting of Mills Plains (although located just outside the region) depicts this lost landscape of vast woodlands extending over hills and plains, and in the foreground its Aboriginal perpetuators (fig. 1). The grassy country that attracted wallabies for Aborigines to hunt was also attractive to pastoralists. Scott (1965) notes that by 1835, following the establishment of markets for Tasmanian wool in England in the 1820s, most of the grasslands and woodlands of the Midlands and Fingal Valley were in the possession of '20,000 acre gentry'. Although there were some similarities between the farming practices of the Aborigines and the pastoralists, the loss of the woodlands resulting from a century and a half of European agriculture is all too obvious. It is not surprising that the remnant vegetation of the broad valleys has the highest priority for conservation in the region. Fortunately, the conservation and economic significance of grassy woodlands and associated grasslands is being increasingly recognised by both private landowners and government.

Ecological relationships in granite-based lowland forest

This section describes variation in granite-based forest, scrub and moorland vegetation of undulating country near Old Chum Dam (in the upstream catchment of the Great Musselroe River). A more detailed account is given by Duncan and Brown (1995). Some analyses of the fauna of the area have also been published (e.g. Taylor & Haseler 1993; Taylor et al. 1993, 1994; Walsh et al. 1994).

Vegetation and environmental data were obtained from 66 plots covering the range of vegetation types in the area. Analysis of species cover/abundance data, using the polythetic divisive programme TWINSPAN (Hill 1979), resulted in twelve interpretable plant groups (communities) being identified. There was a trend in floristic composition from tall *Acacia melanoxylon* and *E. obliqua* forests with mesomorphic understoreys, to scrub and moorlands with diverse low shrub and round strata of scleromorphic species. Some species (e.g. *Gleichenia microphylla*, *Xanthorrhoea australis*, *Atherosperma moschatum*) had a high fidelity to particular communities, while others (e.g. *E. obliqua*, *E. amygdalina*, *Pteridium esculentum*, *Gonocarpus teucrioides*) occurred in most of the groups delineated. The data were ordinated using hybrid multi-dimensional scaling (Minchin 1987).
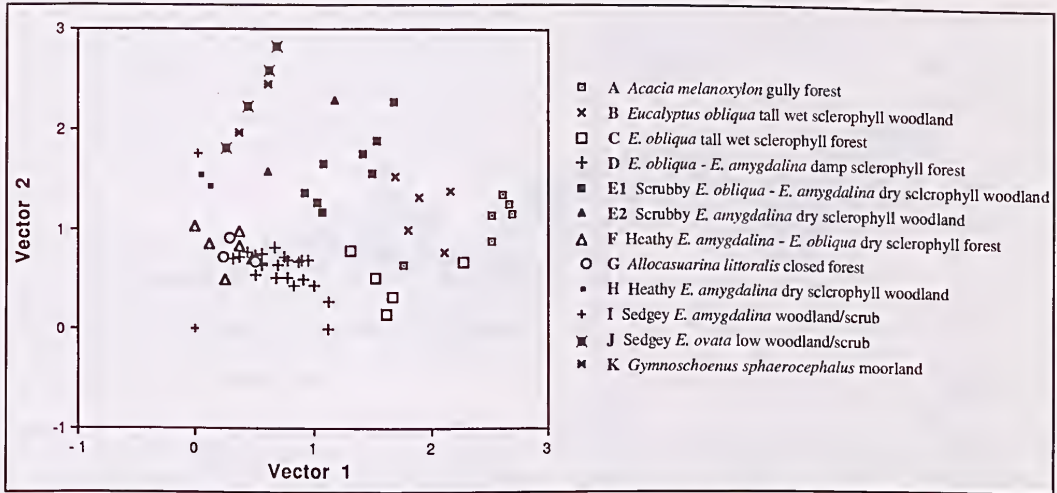
Fig. 2. Ordination of the vegetation in the Old Chum Dam area (from Duncan & Brown 1995).

Plotting of site scores on the primary and secondary axes of the ordination (fig. 2), and analyses of soil samples and other physical data, suggested that several factors, some interrelated, were responsible for the distribution of native vegetation in the area. The relationship between landform and distribution of plant communities in the Old Chum Dam area is shown in figure 3a. The general responses of the vegetation to moisture availability, drainage and fire are indicated in figure 3b.

Riparian *A. melanoxylon* forest (Group A) occupies the most 'favourable' sites, such as well-defined gullies and creekline corridors. These are relatively shaded, humid and protected from fire, have moderately high soil moisture contents, and have higher proportions of silt and clay than sites supporting other forest groups. The riparian forests grade into tall *E. obliqua* wet sclerophyll woodland and forest (Groups B and C) on sites which are less humid, but still shaded and burnt infrequently (typically at intervals greater than 30 years). At the other extreme, heathy *E. amygdalina* dry sclerophyll forest (Group F), sedgey woodland/scrub (Groups I and J) and moorland (Group K) occupy 'unfavourable' sites, which are more prone to drought, have higher fire frequencies (typically at intervals less than 20 years), and have sandy soils with low moisture contents (Group F) or have impeded drainage (Groups I, J and K). The influence of drainage on floristic composition can be seen by the position on the ordination (fig. 2) of scrubby woodlands (Groups E1 and E2), which have a dense understorey dominated by *Melaleuca* spp. and *Leptospermum* spp. and occupy poorly drained soaks and basins associated with minor drainage lines.

The occurrence of *A. moschatum* as a secondary tree in riparian *A. melanoxylon* forest, and an abundance and diversity of epiphytic species, indicates a period of over 100 years between fires for this vegetation type (Neyland 1991). A long period (over 200 years) without fire is

likely to result in sassafras dominating such sites, and blackwood being represented by sporadic trees and abundant soil-stored seed. A fire-free interval of at least 30 years is surmised for *E. obliqua* tall wet sclerophyll forests and woodlands, with the intervals on more humid sites, characterised by the presence of trunked ferns, epiphytic ferns and young sassafras, probably approaching that of riparian *A. melanoxylon* forest.

Fires are more frequent in heathy dry sclerophyll forests and woodlands on better drained sites, but are generally less intense than those resulting in conflagrations in wet forest types. Frequent cool fires are probably responsible for low densities and diversities of understorey shrubs and the dominance of bracken on many sites. Scrubby woodlands, occupying drainage basins and soaks, appear to have escaped burning for at least 20 years, despite supporting dense understoreys of flammable myrtaceous shrubs. Moist soil and litter conditions may have inhibited the spread, into scrubby woodlands, of cool fires burning in adjacent heathy forests.

Copses of *Allocasuarina littoralis* closed forest (Group G) occur locally on broad ridges which have not been burnt for at least 30 years. These stands are mainly surrounded by heathy forests with open understoreys, which tend to carry ground fires of low intensities rather than crown fires. The cool fires are unable to penetrate far into the *A. littoralis* forests, because of the relatively non-flammable foliage and litter of the dominants (Dickinson & Kirkpatrick 1985), and the sparse nature of the understorey under the dense canopy. A similar situation has been described for *A. verticillata* forest (Harris & Kirkpatrick 1991a).

Flammable myrtaceous species, epacrids and graminoids dominate low woodlands, scrub and moorlands on sites with impeded drainage. In warmer areas of the State, such as the Northeast, rates of fuel accumulation of up to 3

Fig. 3. Relationships between vegetation and environment in the Old Chum Dam area (from Duncan & Brown 1995).

(a) Representation of changes in the vegetation across the landscape (approx. vertical exaggeration 3:1), indicating structural differences between communities. Inset shows location of the study area.

(b) Response of plant communities to changes in three major environmental variables.

Plant groups: (A) *Acacia melanoxylon* gully forest; (B) *Eucalyptus obliqua* tall wet sclerophyll woodland; (C) *E. obliqua* tall wet sclerophyll forest; (D) *E. obliqua - E. amygdalina* damp sclerophyll forest; (E1) Scrubby *E. obliqua - E. amygdalina* dry clerophyll woodland; (E2) Scrubby *E. amygdalina* dry sclerophyll woodland; (F) Heathy *E. amygdalina - E. obliqua* dry sclerophyll forest; (G) *Allocasuarina littoralis* closed forest; (H) Heathy *E. amygdalina* dry sclerophyll woodland; (I) Sedgey *E. amygdalina* woodland/scrub; (J) Sedgey *E. ovata* low woodland/scrub; (K) *Gymnoschoenus sphaerocephalus* moorland.

tonnes per hectare per year in moorlands (Marsden-Smedley 1994) encourage a fire regime which, coupled with seasonal waterlogging on these sites, maintains the dominance of buttongrass and other graminoids (Kirkpatrick & Wells 1987). Fires are less frequent in low woodlands and scrub, ensuring the replacement of shrub species from rootstock or seed following fire in this vegetation type.

The gross trends in the Old Chum Dam area are consistent with those occurring in several other lowland forested areas in north and east Tasmania. They include the Great Northern Plain (Kirkpatrick & Wells 1987), West Tamar (Brown & Buckney 1983), Schouten Island (Harris & Kirkpatrick 1982); Tasman Peninsula (Brown & Duncan 1989) and the Meehan Range (Kirkpatrick & Nunez 1980). Similar trends have been reported for comparable environments on the southeast Australian mainland (e.g. Forbes et al. 1982; Keith & Sanders 1990).

Conclusions

Lowland forests and woodlands occupy about 400 000 ha in northeast Tasmania, and are the most widespread

vegetation type in the region. The vascular flora and communities of the Northeast lowland forests have strong affinities with those occurring on the southeast Australian mainland. However, about 60 forest species, including some that are absent from other regions of the State, are considered to be rare or threatened in Tasmania. The non-vascular flora is poorly known and warrants further research.

The distribution of species and communities, at a regional level, is influenced by landform, climate, soil characteristics, drainage, fire history and land use. Analyses of vegetation patterns and environmental variables in the Old Chum Dam area show that these factors also operate at a local scale.

Historical records and circumstantial evidence indicate that the lowland forests and woodlands have been affected by Aboriginal land use and burning practices. A heavier tread on the landscape has resulted from European settlement, agriculture, forestry and mining, and by the fire regimes and the introduction of exotics, including the fungal pathogen *Phytophthora cinnamomi*, associated with some of these activities. About 30 000 ha of lowland forests are in existing or proposed reserves, but off-reserve conservation management will be important in maintaining regional biodiversity.

Acknowledgements

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The Relationship Between Highland Forest and Grassland in the Northeast

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Abstract

The factors of Aboriginal and European land use in the highland of northeast Tasmania that have determined the present structure of the vegetation are discussed. Results are presented from experiments and vegetational surveys that were aimed at elucidating the ecological processes that drive vegetational changes in the area. The importance of those processes in the formulation of practices for conserving the various vegetational types that occur during secondary vegetational succession is considered briefly.

Introduction

In the early 1960s, soon after timber-harvesting operations commenced, it became apparent that the forests of the upper levels of the Mt Maurice plateau presented two fascinating silvicultural problems. The first was that mature and younger eucalypts were dying where an understorey of rainforest species had developed. The second was that seedling regeneration of eucalypts was either failing to establish, or, following establishment, was dying out on those sites on which tussock grasses (*Poa* spp.) were dominant. Silviculture is applied ecology, and so it was an ecological approach that I adopted in a study of these problems. In fact, on the Mt Maurice plateau, and in several similar areas in the north of the State, a most interesting ecological phenomenon was occurring. In a broad band that extends from the Arthur River in the west to Pyengana in the east, broken only by the lowland between the Western Tiers and Mt Barrow, are highlands in which rainfall is sufficient to support rainforest on all topographic locations. Yet at the time of European settlement these areas carried a complex vegetation of rainforest, open eucalypt forest and tussock-grass plains.

Trees are long-lived; they can attain an age of 400-500 years in the case of eucalypts and myrtle, and more than three times that age for Huon and King Billy Pines. During a human lifetime, few changes appear to occur in a mature forest, except where it has been felled and regenerated in the course of forestry operations. This impression of stability can be misleading, though, and in some parts of Tasmania's highlands great changes in the natural forest have occurred since early last century in response to the change from Aboriginal to European land use.

It is well-documented that the Aborigines used fire extensively (Thomas 1994). Early explorers noted that travel routes around the coast, and between coastal wintering areas and highland summer hunting grounds were kept free of scrub by the frequent use of fire. Annual and probably systematic controlled burning was used to promote the growth of fresh browse and, therefore, to concentrate game for ease of hunting. Although fire may have also been used in warfare, its indiscriminate or careless use would have been dangerous to the people themselves, and destructive to the environment on which they depended for a living, and so was probably avoided. Nevertheless, we can be sure that extensive fires did occur by accident during exceptionally hot, dry years, since evidence for this is present in the form of fire scars of various ages.

Evidence from pollen analysis, and carbon-dating of cave and river deposits, indicates that Aborigines had used fire in Tasmania for more than 23 000 years, and that during the last several thousand years the climate has been relatively stable (Macphail 1980). Before its disruption following contact with Europeans, Aboriginal society also appears to have been very stable, and so it is likely that an equilibrium would have been established between the natural vegetation and Aboriginal use of fire (Ellis & Thomas 1988). The nature of this equilibrium and the effect upon it of subsequent changes in frequency and intensity of fire, is of special interest in highland areas such as the Mt Maurice plateau.

Both historical evidence and recent observations have confirmed that on level areas above about 600 m elevation, and on most areas over 800 m, rainforest when burned is replaced by grassland rather than by prickly shrubs and bracken (fig. 1). Archaeological studies have shown that such areas were used by Aborigines, probably

Fig. 1. Pyrogenic grassland from a fire in 1908. Myrtle logs in foreground, silver wattle with understorey of rainforest in background.

Fig. 2. Pioneer eucalypt on pyrogenic grassland from a fire about 1780, surrounded by annuli of younger cohorts.

Fig. 3. Four overlapping fire scars on a dead eucalypt in a stand of myrtle unburned for about 130 years.

as summer hunting grounds. Their activities evidently produced the large tracts of grassland to which early surveyors gave the evocative names Paradise Plains, Diddleum Plains, Emu Plains, Borradaile Plains, Middlesex Plains and Surrey Hills. Where burning was repeated, eucalypts became established in the grassland - probably from seed brought in by chance by Aborigines. Pioneer stands of one or a few trees expanded by means of seedling regeneration - which became established from time to time when a fire occurred in conjunction with a favourable season - to form park-like stands and even closed forest (fig. 2). However, on sites that were prone to frost and where burning was very frequent, grassland, once induced, could persist indefinitely. Boundaries between rainforest, eucalypt forest and grassland were sharp and relatively stable, normally with little incursion of fire into the often large blocks of rainforest (Ellis 1985).

Changes since European settlement

With the removal of the Aborigines, by about 1835, there occurred major changes in the frequency and intensity of fires in the highlands. In some areas regular burning of grassland was in fact continued by graziers, who substituted sheep and cattle for wallaby, and this preserved the vegetational status quo for many years. In other areas of the Northeast, fires associated with prospecting and mining operations destroyed large tracts of rainforest that had survived as such for hundreds and probably thousands of years and turned them to grassland. Over much of the highland, however, the incidence of fire decreased or ceased altogether. As a result, by late last century '*many open plains, especially in the north, which were formerly known as favourite resorts of the blacks subsequently became overgrown with forest through the discontinuance of these annual burnings* [p. 177]...*These open spaces were formerly more numerous, being kept clear by burning. Many of them have become overgrown with timber since the removal of the natives* [p. 181]' (Walker 1897, pp. as indicated).

The changes in the vegetation of an area that have occurred over 200-300 years can be reconstructed by

observing the remains of trees and other plants, and by the intrepretation of signs of damage on living trees. Thus, counts of the annual growth rings on borings taken from many trees were used to determine tree ages, whilst the number of rings in the overgrowths of fire scars was used to date fires. The presence of a number of overlapping fire scars on dead eucalypts that are now engulfed in rainforest 140 or more years in age gave clear indication of a dramatic decrease in frequency of fires since early last century (fig. 3). The presence of old, wide-crowned trees with low branches (open-grown form) growing in a stand of tall, straight, younger trees showed that what had once been a park-like woodland of widely spaced trees had become a dense forest. Cutting into old, decayed logs that were barely visible beneath the moss in a rainforest revealed a eucalypt's pattern of grain, and showed that eucalypts had once occupied the area. Similarly, small fragments of charred wood on that part of Paradise Plains that predated settlement were found to be myrtle, and this, together with ring counts of open-grown eucalypt trees on the Plains, showed that rainforest originally covered the area that now carries grassland, and that it had been destroyed before 1780. From such observations - one might call it 'botanical sleuthing' - the sequences of change since settlement were recognised in two 'reference' areas on the Mt Maurice plateau (fig. 4). The first experienced a decrease in incidence of fire, while the second experienced at first an increase in intensity and frequency of fire, and then a decrease during the last 40 years.

Reference Area A

It is apparent that 160 years ago the area south of Mt Maurice carried tall, uneven-aged stands of gum-top stringybark (*Eucalyptus delegatensis*), most probably over grass and a sparse cover of prickly beauty (*Pultenaea juniperina*), cheeseberry (*Cyathodes parvifolia*) and guitar plant (*Lomatia tinctoria*). There were isolated individuals of myrtle (*Nothofagus cunninghamii*), tea tree (*Leptospermum lanigerum*) and silver wattle (*Acacia dealbata*) present. Narrow bands of rainforest - corridor forest - occurred along streams in

Fig. 4. Location of the Mt Maurice plateau and two reference areas.

some of the shallow valleys on the plateau, and there were extensive stands of rainforest in the deep valleys facing Ringarooma. North of Mt Maurice, towards Scottsdale, were the Maurice High Plains. These carried grass at the time of settlement, and in 1978 a local farmer recalled that they were used for summer grazing until the early part of this century.

Today the picture is entirely different (table 1). Dense stands of tea tree and myrtle have occupied the Maurice High Plains and the grass has all but disappeared. To the

south of Mt Maurice more than 90% of the eucalypt stands have been undergrown with various kinds of rainforest vegetation and, as a result, many are either dead or dying. Only on two small areas that were burned and grazed until the 1950s is grass now an important part of the ground cover.

Reference Area B

A contrary picture emerges from an area of 180 ha that encompasses Paradise Plains and rainforest to the east of the Plains. One hundred and sixty years ago the Plains were smaller than they are at present, and carried a few open-grown trees of *E. delegatensis* and myrtle and, perhaps, a few groves of silver wattle. Corridors of rainforest occurred along the streams, and at the edge of the dense block of rainforest that formed the eastern boundary of the Plains, dead trees and burned logs showed where Aboriginal fires had been eroding its margin. About 1860, a fire that originated probably from agricultural operations in the Ringarooma Valley burned rainforest stands on the north of the Plains. In 1908 a fire associated with mining operations burned a tract of rainforest on the eastern side of the Plains and extended the area of grassland. Burning in association with grazing was practiced, but this was reduced from about 1940 onwards and ceased about 1960. Since then there has been an invasion of the grassland by tea tree, and of the eucalypt, tea tree and wattle stands by rainforest species (table 1).

Table 1. Proportions (%) of the vegetational types on two reference areas at present and probable proportions at time of European settlement (from Ellis 1985).

	Area A (Mt Maurice)		Area B (Paradise Plains)	
	1834	1984	1834	1984
Old-growth rainforest on well-drained sites and old-growth rainforest on poorly drained sites	5.0	4.5	41.5	15.5
Even-aged secondary rainforest on well-drained sites	<1.0	31.0	<1.0	4.0
Even-aged secondary rainforest on poorly drained sites	<1.0	8.0	<1.0	2.5
Dead and dying eucalypts over uneven-aged secondary rainforest	<5	23.0	0	<0.1
Eucalypts over mature gap-phase shrubs	<5	27.0	0	3.0
Eucalypts over young gap-phase and sclerophyll shrubs	80.0	6.5	0	12.5
Eucalypts over grass		0	10.0	6.5
Wattle over grass and shrubs	0	0	<10.0	12.0
Uneven-aged tea tree over grass	<1.0	0	0	5.5
Grassland less than 100 years old	0	0	42.0	9.0
Grassland more than 100 years old	0	0	?	28.5
Open wetland	8.0	0	<1.0	<1.0

Secondary forest succession

When, in about 1830, regular burning in most of the Mt Maurice area ceased, the uneven-aged eucalypt forest with its ground cover of grass and fire-tolerant shrubs became invaded by an understorey of rainforest gap-phase shrubs (figs 5, 6). These are small trees that occur normally as transients in the gaps that form from time to time in rainforests when one or a few trees are blown down or die. The group includes pepper (*Tasmannia lanceolata*), waratah (*Telopea truncata*), native currant (*Coprosma nitida*), geebung (*Persoonia gunnii*), cheesewood (*Pittosporum bicolor*) and ironwood (*Notelaea ligustrina*), the seeds of which are dispersed mainly by birds. They grow luxuriantly beneath the shelter of eucalypts in the highland climate, and in 50 to 100 years form a dense understorey that suppresses the grass and develops a layer of moist litter. Tea tree and silver wattle may also increase. These sheltered conditions are suitable for the establishment of the rainforest dominants myrtle, sassafras (*Atherosperma moschatum*) and celery-top pine (*Phyllocladus aspleniifolius*). Myrtle seed is wind-dispersed and comes from isolated, open-grown trees present beneath eucalypts, sassafras seed comes from corridor stands in gullies and celery-top pine seed is dispersed by birds. At 100-120 years of age, the gap-phase shrubs decline and die and the rainforest dominants take over, gradually forming a dense, fully stocked stand. By the time the understorey is about 80 years of age the eucalypts have usually begun to decline, with the younger trees dying first. At 120 years nearly all the eucalypts are dying or dead (fig. 7). This sequence is an example of secondary forest succession; it is the process by which rainforest re-establishes itself after it has been destroyed or excluded from an area by fire. The eucalypts appear to provide ideal conditions for the establishment of the gap-phase shrubs and these in turn provide conditions suitable for the rainforest dominants, while at the same time conditions develop that are unsuitable even for mature and hitherto vigorous eucalypts. These sequences are illustrated in figure 8.

As one might expect, succession to rainforest occurs more rapidly in cool, moist conditions than in warmer and drier conditions. It is therefore more rapid at higher than at lower elevations, more rapid in gullies than on slopes and more rapid on south-facing than on north-facing aspects. Under the most favourable cool, moist conditions the transition from eucalypt over grass to rainforest may take about 100 years and the eucalypts start to die after 60 years. Under the least favourable warm, dry conditions the transition can take much longer - perhaps 200 years - and the eucalypts start to die after 100-120 years. On level areas subject to severe radiation frosts, grass can persist for many decades. A combination of frost, animal browsing and (sometimes) poor drainage can maintain small grassy plains long after the surrounding area has succeeded to rainforest. These plains serve as refugia for subalpine grassland species, from which they can recolonise adjacent areas after a fire. On the Mt Maurice plateau rainforest now occupies areas from which it had been excluded by fire probably for several thousand years; it is also clear that grassland and grassland refugia must have existed throughout that time.

The mechanism by which rainforest kills eucalypts is still unclear. In many areas below 800 m, *E. delegatensis* lives out its normal life span of 400 years or more over rainforest. Under cool, moist conditions above about 800 m it seems probable that substances produced by the rainforest trees, or during decay of their litter by fungi and bacteria, are toxic to the eucalypt or to its normal mycorrhizal fungi. Such examples of 'biological warfare', known as allelopathic interactions, have been noted elsewhere in forests. The decline of the eucalypts can be halted and their health improved if the understorey is felled and burned, and eucalypts have remained perfectly healthy on areas that are burned sufficiently regularly to prevent a rainforest understorey being developed at all (Ellis et al. 1980).

An apparent antagonism between grasses and some trees has been observed in several parts of the world. In the Tasmanian highlands, periodic fires enable eucalypt seedlings to establish in grassland. However, if burning ceases, even well-established seedlings 2 to 3 m high may stop growing and eventually die - although pole-sized and older trees are not so affected. On the Mt Maurice plateau tea tree is the only tree species that can establish in grassland in the absence of fire (fig. 9). It then acts as a nurse beneath which rainforest species appear once grasses have been suppressed (fig. 10). Sometimes, on the edge of a stand, tea tree can act also as a nurse for eucalypts.

The suppressive effect of rainforest and grassland on the growth of eucalypts can be mirrored in laboratory pot experiments, by using fresh soil from rainforest and grassland stands of various ages planted with germinating eucalypt seed. The results from a series of such

Fig. 5. Frequently burned, multi-aged eucalypt stand one year after fire.

Fig. 7. Dead eucalypt stand over gap-phase shrubs and rainforest more than 120 years since last fire.

Fig. 6. Eucalypt stand, once frequently burned, now undergrown with gap-phase rainforest shrubs, about 80 years after fire.

Fig. 8. Secondary succession in rainforest in northeast Tasmania. Dashed lines imply fire, unbroken lines no fire (from Ellis 1985).

Fig. 9. Tea tree invading Paradise Plains.

Fig. 10. Dense tea tree stand undergrown with rainforest species, Paradise Plains.

experiments are shown in table 2. The suppressive effect was most pronounced in soil from late successional rainforest (Ellis & Pennington 1992). In concurrent field studies it was found that the inhibition of growth of eucalypt seedlings planted in grassland was overcome slowly when the grass was killed by using a herbicide before planting and was overcome rapidly when the grass was killed and the soil also sterilised by the use of chemicals.

had once carried 40-45 m tall eucalypt forest, but now carry dense rainforest below dead and dying eucalypts.

All the stands were on granitic soils that were remarkably uniform in their chemical characteristics, other than in the top 10 cm. The rainforest soil was found to have slightly higher concentrations of both total nitrogen and organic matter than did the grassland and eucalypt soils, but the latter were less acidic and had higher concentrations of

Table 2. Growth of *Eucalyptus* seedlings at age 16 weeks in soil from vegetational types in a successional sequence (from Ellis & Pennington 1992).

	Years since last fire	Dry weight of leaves (g)
Healthy eucalypts, young shrubs and grass	1	5.9
Healthy eucalypts, mature shrubs and grass	c. 50	4.3
Unhealthy eucalypts, old shrubs	c. 90	2.7
Dead and dying eucalypts, secondary rainforest	c. 120	0.1
Dead eucalypts, secondary rainforest	c. 160	0.8
Primary rainforest	>500	1.4

In laboratory pot experiments the inhibitory factors in both rainforest and grassland soils were shown to be overcome when germinating eucalypt seed was planted in inhibitory soil that had been inoculated with 20% by weight of soil from a healthy, recently burned eucalypt stand: growth in the inoculated soil was as rapid as that in 100% non-inhibitory soil (Ellis & Pennington 1992). Microscopic inspection of the roots of the seedlings used in those experiments suggested that inhibition could be the result of microbiological antagonisms that develop in unburned soil and affect adversely the mycorrhizal associations of the eucalypts. There appeared to be a succession of microflora in the soil that was complementary to the forest succession above ground.

The effect of fire on soil

The effect of fire on soil is the subject of much speculation and not a little controversy. Studies of the Mt Maurice soils indicate that the chemical effects are small, and that burning is beneficial to the eucalypts (Ellis & Graley 1987). In table 3 are shown the concentrations of nutrients in the top 10 cm of samples of soil taken from seven stands of grassland, and from 11 stands of eucalypts with a grassy ground cover. All of them had been burned more or less regularly since European settlement and most of them for a very long time before that. These are compared with the concentrations of nutrients in soils from 12 stands of rainforest. Five of those rainforest stands had been unburned for probably 500 years and seven had been unburned for about 160 years. The latter

both total phosphorus and total and exchangeable base nutrients than did the rainforest soil.

It may come as a surprise to discover that soil from forest that had been burned regularly, probably for several hundreds of years, should have a generally higher nutrient content than that from forest that had remained unburned for a similar time. The explanation may be as follows: when litter and debris from rainforest are decomposed by biological processes on the floor of the forest, the acidic products of decomposition leach nutrients from the soil under the prevailing conditions of high rainfall and cool temperatures. Indeed, values for pH taken *in situ* under rainforest were sometimes found to be as low as 3.5 to 4.0, which is rather like weak vinegar. In contrast, when litter and debris of grass and eucalypt forest are decomposed by fire, no such acidic products are formed; nutrients are retained in the upper few centimetres of soil so that, with the exception of nitrogen, and provided that fires are neither too frequent nor too intense, there is less loss of nutrient than occurs with acid leaching in the unburned forest. Nitrogen will be lost with each fire, but this loss appears to be small and is largely offset by the fact that the nitrogen-fixing leguminous species *P. juniperina* and *A. dealbata* occur intermittently over space and time in most of the eucalypt stands; neither they nor other legumes occur in old rainforest stands. The nitrogen fixed by these species can result in high local levels of both total and available nitrogen in the soil (Ellis & Pennington 1989).

Conclusion

By judicious use of fire it is probable that the Aborigines established a pattern of vegetation in cool, moist highlands that was suited to their needs. If we accept that pattern as being suited also to our present-day needs, be those the production of wood, conservation of species and ecosystems, re-establishment of an early nineteenth-century landscape or simply for recreation, then we must implement practices that will ensure its perpetuation. I have presented evidence that the practice that created the original vegetational pattern on the Mt Maurice plateau was based on the frequent and controlled use of fire, and it would have been very labour-intensive. It is most doubtful that such a scheme of management would be considered to be practicable now, and certainly not for large areas.

On much of the Mt Maurice plateau, secondary forest succession in the absence of fire, and the clearfelling and burning of eucalypt stands conducted in the 1970s, have wrought great changes in the original - that is, the eighteenth-century - vegetational pattern. However, a sufficient variety of ecosystems remains in reserved and burned eucalypt stands along the Ben Ridge Road, in the southern part of the Mt Maurice Forest Reserve and adjacent to Paradise Plains for an active program of management by regulation of fire to re-establish and perpetuate examples of all the important vegetational types. But time is running out: rainforest is asserting its ecological dominance of the plateau and appears set to complete a process that commenced more than 5 000 years ago.

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Table 3. Concentration of nutrients in the surface soil (0-10 cm) beneath eucalypt forest, rainforest and grassland (from Ellis & Graley 1987).

		Grassland	Eucalypt	Rainforest
pH		5.3	5.1	4.3
Organic matter (% dry soil)		17.2	17.3	20.2
Total nutrients (% dry soil)	N	0.42	0.37	0.45
	P	0.065	0.066	0.040
	K	2.70	2.55	2.65
	Ca	0.36	0.35	0.25
	Mg	0.14	0.15	0.09
Exchangeable bases (Me/100 g)	Ca	2.60	4.33	1.68
	Mg	0.99	1.17	0.94
	K	0.47	0.47	0.36

Ferns and Allied Plants of Northeast Tasmania

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Abstract

Seventy-eight species of ferns and fern allies have been recorded from northeast Tasmania. This figure represents slightly more than three-quarters of the State's pteridophyte flora. The greatest diversity and abundance of species occurs in wet forest. No species is confined to the Northeast within the State, but four species, *Calochlaena dubia*, *Hypolepis muelleri*, *Phylloglossum drummondii* and *Selaginella gracillima*, have their Tasmanian distributions centred in the region. Two species, *Isoetes elatior* and *I. gunnii*, are endemic to Tasmania. All except four taxa are known from within Tasmanian reserves, five species are inadequately reserved and seven species are either endangered or possibly extinct within the region.

Introduction

The ferns and fern allies (collectively known as pteridophytes) differ from the other vascular plants (dicotyledons, monocotyledons and gymnosperms) in that they are flowerless and reproduce from spores. They differ from the other cryptogams (mosses, liverworts, lichens, algae and fungi) chiefly by their possession of an internal vascular system. The true ferns make up the single large plant group Filicopsida, which in Tasmania is represented by 37 genera and 81 species (Garrett, in press). The fern allies comprise three distinct plant groups, all different from but closely related to the true ferns. Two of these groups are represented in Tasmania: Psilotopsida (one genus, three species) and Lycopsida (six genera, 17 species) (Garrett, in press). The fern allies are differentiated from the true ferns by their sporangia, which are borne singly at the leaf bases; by having leaves containing single unbranched veins; and by the absence of true fronds.

Thirty-six per cent of the State's pteridophyte species are widespread in Tasmania and are common to abundant in a particular habitat or variety of habitats. Moist and sheltered sites, such as those found in rainforest, in wet sclerophyll forest and in deep gullies within dry sclerophyll forest, contain the greatest diversity of species. Other species are less common and more restricted in distribution due to more rigid habitat or climatic requirements.

Garrett (1992) gives a brief account of each species' habitat and distribution in the Northeast, with some additional species being listed due to a broader interpretation of the region (included, for example, were off-shore islands, Elephant Pass and Freycinet Peninsula). As a consequence, the species *Auogramma leptophylla*, *Cyathea cunninghamii*, *C. marcescens* and *Tmesipteris parva* as listed in that survey have not been included in this paper. Also excluded is the subspecies *quadrivalens* of *Asplenium trichomanes* from Flinders Island, while subspecies *trichomanes* is now confirmed and included here. Garrett (1992) dealt only with those species seen *in*

situ by the author. The current paper also includes *Azolla filiculoides*, *Botrychium lunaria*, *Doodia caudata* and *Schizaea asperula*, being known in the Northeast only as specimens lodged in either the Tasmanian Herbarium, the National Herbarium of Victoria, the National Herbarium of New South Wales, or the herbarium of the Queen Victoria Museum and Art Gallery. Nomenclature in this paper follows Garrett (1992) with the exceptions listed in table 1.

Table 1. Recent name changes used in this paper.

OLD NAME	NEW NAME
Allantodia australis	*Diplazium australe*
Culcita dubia	*Calochlaena dubia*
Lycopodium australianum	*Huperzia australiana*
Lycopodium laterale	*Lycopodiella lateralis*
Lycopodium varium	*Huperzia varia*
Microsorum diversifolium	*Phymatosorus pustulatus*
Tmesipteris billardierei	*Tmesipteris obliqua*

Census and distribution of northeast Tasmanian ferns

The 78 species of pteridophytes (63 ferns and 15 fern allies) recorded in northeast Tasmania are listed systematically in table 2. The total represents slightly more than three-quarters of the State's pteridophyte flora.

Two Northeast species, *Isoetes elatior* and *I. gunnii*, are endemic to Tasmania. This compares with seven endemic pteridophyte species for the whole State (out of exactly 100 indigenous species) and five endemic species out of 65 species in southwest Tasmania. Not one of the 78 species is confined (within Tasmania) to the region. However four species, *Calochlaena dubia*, *Hypolepis muelleri*, *Phylloglossum drummondii* and *Selaginella gracillima*, have their Tasmanian distributions centred in the Northeast. *Calochlaena dubia* more or less hugs the north Tasmanian coastline as far west as Circular Head and extends to Bicheno on the east coast, but most records

Table 2. Census of pteridophyte species recorded from northeast Tasmania, showing presence in predominant habitat: (1) wet forest, (2) dry forest, (3) coastal heathland, (4) wetland scrub, (5) alpine, (6) aquatic, (7) littoral.

	1	2	3	4	5	6	7
(FERN ALLIES)							
ISOETACEAE							
Isoetes drummondii A. Braun	-	-	-	-	-	X	-
I. elatior F. Muell. ex A. Braun	-	-	-	-	-	X	-
I. gunnii A. Braun	-	-	-	-	-	X	-
I. muelleri A. Braun	-	-	-	-	-	X	-
LYCOPODIACEAE							
Huperzia australiana (Herter) Holub	-	-	-	-	X	-	-
H. varia (R. Br.) Trev	X	-	-	-	-	-	-
Lycopodiella lateralis (R. Br.) B. Øllg.	-	-	X	-	-	-	-
Lycopodium deuterodensum Herter	-	-	X	-	-	-	-
L. fastigiatum R. Br.	-	-	-	-	X	-	-
L. scariosum Forst. f.	-	-	-	-	X	-	-
Phylloglossum drummondii Kunze	-	-	X	-	-	-	-
PSILOTACEAE							
Tmesipteris elongata P.A. Dangeard	X	-	-	-	-	-	-
T. obliqua Chinnock	X	-	-	-	-	-	-
SELAGINELLACEAE							
Selaginella gracillima (Kunze) Alston	-	-	X	-	-	-	-
S. uliginosa (Labill.) Spring	-	-	X	-	-	-	-
Total fern ally species from each habitat	**3**	**0**	**5**	**0**	**3**	**4**	**0**
(FERNS)							
ADIANTACEAE							
Adiantum aethiopicum L.	-	X	-	-	-	-	-
Cheilanthes austrotenuifolia Quirk & Chambers	-	X	-	-	-	-	-
C. sieberi Kunze	-	X	-	-	-	-	-
Pellaea calidirupium Brownsey & Lovis	-	X	-	-	-	-	-
P. falcata (R. Br.) Fée	X	-	-	-	-	-	-
ASPLENIACEAE							
Asplenium bulbiferum Forst. f.	X	-	-	-	-	-	-
A. flabellifolium Cav.	-	X	-	-	-	-	-
A. flaccidum Forst. f.	X	-	-	-	-	-	-
A. obtusatum Forst. f.	-	-	-	-	-	-	X
A. terrestre Brownsey	X	-	-	-	-	-	-
A. trichomanes L. subsp. *trichomanes*	-	X	-	-	-	-	-
Pleurosorus rutifolius (R. Br.) Fée	-	X	-	-	-	-	-
AZOLLACEAE							
Azolla filiculoides Lam.	-	-	-	-	-	X	-
BLECHNACEAE							
Blechnum cartilagineum Swartz	-	X	-	-	-	-	-
B. chambersii Tindale	X	-	-	-	-	-	-
B. fluviatile (R. Br.) E.J. Löwe ex Salomon	X	-	-	-	-	-	-
B. minus (R. Br.) Ettingsh.	-	-	-	X	-	-	-
B. nudum (Labill.) Mett. ex Luerss.	X	-	-	-	-	-	-
B. patersonii (R. Br.) Mett.	X	-	-	-	-	-	-
B. penna-marina (Poiret) Kuhn	-	-	-	-	X	-	-
B. vulcanicum (Blume) Kuhn	-	-	-	-	X	-	-
B. wattsii Tindale	X	-	-	-	-	-	-
Doodia caudata (Cav.) R. Br.	-	X	-	-	-	-	-
D. media R. Br.	-	X	-	-	-	-	-
CYATHEACEAE							
Cyathea australis (R. Br.) Domin	X	-	-	-	-	-	-
DENNSTAEDTIACEAE							
Histiopteris incisa (Thunb.) J. Smith	X	-	-	-	-	-	-

Hypolepis amaurorachis (Kunze) Hook.	X	-	-	-	-	-	-
H. glandulifera Brownsey & Chinnock	X	-	-	-	-	-	-
H. muelleri Wakefield	-	-	-	X	-	-	-
H. rugosula (Labill.) J. Smith	X	-	-	-	-	-	-
Pteridium esculentum (Forst. f.) Cockayne	-	X	-	-	-	-	-
DICKSONIACEAE							
Calochlaena dubia (R. Br.) M.D. Turner & R.A. White	-	X	-	-	-	-	-
Dicksonia antarctica Labill.	X	-	-	-	-	-	-
DRYOPTERIDACEAE							
Lastreopsis acuminata (Houlston) Morton	X	-	-	-	-	-	-
Polystichum proliferum (R. Br.) C. Presl	X	-	-	-	-	-	-
Rumohra adiantiformis (Forst. f.) Ching	X	-	-	-	-	-	-
GLEICHENIACEAE							
Gleichenia alpina R. Br.	-	-	-	-	X	-	-
G. dicarpa R. Br.	-	-	-	X	-	-	-
G. microphylla R. Br.	-	-	-	X	-	-	-
Sticherus tener (R. Br.) Ching	X	-	-	-	-	-	-
GRAMMITIDACEAE							
Ctenopteris heterophylla (Labill.) Tindale	X	-	-	-	-	-	-
Grammitis billardierei Willd.	X	-	-	-	-	-	-
G. magellanica Desv.	X	-	-	-	-	-	-
G. poeppigiana (Mett.) Pichi-Serm.	-	-	-	-	X	-	-
HYMENOPHYLLACEAE							
Hymenophyllum australe Willd.	X	-	-	-	-	-	-
H. cupressiforme Labill.	X	-	-	-	-	-	-
H. flabellatum Labill.	X	-	-	-	-	-	-
H. marginatum Hook. & Grev.	X	-	-	-	-	-	-
H. peltatum (Poiret) Desv.	X	-	-	-	-	-	-
H. rarum R. Br.	X	-	-	-	-	-	-
Polyphlebium venosum (R. Br.) Copel.	X	-	-	-	-	-	-
LINDSAEACEAE							
Lindsaea linearis Swartz	-	-	X	-	-	-	-
OPHIOGLOSSACEAE							
Botrychium lunaria (L.) Swartz	-	-	-	-	X	-	-
Ophioglossum lusitanicum L.	-	-	X	-	-	-	-
OSMUNDACEAE							
Todea barbara (L.) T. Moore	-	-	-	X	-	-	-
POLYPODIACEAE							
Phymatosorus pustulatus (Forst. f.) Large, Braggins & Green	X	-	-	-	-	-	-
PTERIDACEAE							
Pteris comans Forst. f.	X	-	-	-	-	-	-
P. tremula R. Br.	-	X	-	-	-	-	-
SCHIZAEACEAE							
Schizaea asperula Wakefield	-	-	X	-	-	-	-
S. bifida Willd.	-	-	X	-	-	-	-
S. fistulosa Labill.	-	-	X	-	-	-	-
WOODSIACEAE							
Cystopteris tasmanica Hook.	-	-	-	-	X	-	-
Diplazium australe (R. Br.) Wakefield	X	-	-	-	-	-	-
Total fern species from each habitat	**32**	**13**	**5**	**5**	**6**	**1**	**1**
Total pteridophyte species from each habitat	**35**	**13**	**10**	**5**	**9**	**5**	**1**

are from the Northeast. *Hypolepis muelleri* is uncommon in Tasmania; all of its larger populations are in the Northeast, with only several smaller populations known from northwest Tasmania and from King and Flinders Islands. *Phylloglossum drummondii* is known only from several localities on the north Tasmanian coastline and on King and Flinders Islands. *Selaginella gracillima* is known from a number of localities on the Northeast coast, as well as near Badger Head, in the Midlands and on Flinders Island.

All four of the just-mentioned species are more common in mainland Australia than in northeast Tasmania, and two of these species extend to New Zealand. Another species, *Gleichenia alpina*, is shared by northeast Tasmania and New Zealand but is not known from mainland Australia. It is interesting to note that although northeast Tasmania is geographically closer to New Zealand than is northwest Tasmania, the fern flora of the latter region appears to display greater similarities with that of New Zealand than does the fern flora of the Northeast (69% of pteridophyte species from northeast Tasmania are shared with New Zealand, compared with 73% from the Northwest botanical region). Two prime examples are *Pneumatopteris pennigera* and *Hypolepis distans*, which are known only from the Northwest (and King Island) in Tasmania, are either rare or absent in mainland Australia, and are otherwise known only from New Zealand.

No pteridophyte species are known to have become naturalised in the Northeast.

Habitat preferences

Ferns are generally regarded as plants of moist, sheltered habitats such as rainforest and deep gullies. While the greatest diversity of species does occur in such habitats, other species grow in seemingly less hospitable environments. In Tasmania, fern habitats can be loosely categorised into the following: wet forest, dry forest, coastal heathland, wetland scrub, alpine, aquatic and littoral (Garrett, in press). Some species may occupy more than one habitat, but in all cases, species are easily assigned to a predominant habitat.

Wet forest. This habitat includes rainforest, wet sclerophyll forest and moist, sheltered gullies within dry sclerophyll forest. Sites within wet forest are almost perpetually moist, being sheltered from the drying effects of sun and wind. Dominant tree species include *Nothofagus cunninghamii*, *Atherosperma moschatum*, *Eucalyptus obliqua*, *E. delegatensis* and *Olearia argophylla*. Terrestrial ferns are common, as are epiphytic ones, with *N. cunninghamii* and *A. moschatum* being popular hosts. Ferns growing in thin, mossy soil layers over rock are also common, mainly on dolerite and granite. Wet forest is widespread from sea level to 800 m or more, and the diversity of pteridophytes is greatest in this habitat. Thirty-five pteridophyte species are predominantly from this habitat (table 2), and typical

species include *Asplenium bulbiferum*, *Blechnum wattsii*, *Dicksonia antarctica*, *Grammitis billardierei* and *Sticherus tener*. A number of species, including *Asplenium flaccidum*, *Diplazium australe* and *Pteris comans*, are restricted to this habitat.

Dry forest. Dry forest ferns occur on low-altitude sites such as dry and sunny hillsides, exposed rock outcrops and beside ephemeral creeks within dry sclerophyll forest. Ferns in this habitat are adapted to relatively harsh, dry conditions, their top growth often dying down over summer months. Thirteen species are predominantly from this habitat (table 2), and typical species are *Adiantum aethiopicum*, *Asplenium flabellifolium* and *Cheilanthes austrotenuifolia*. Most dry forest ferns are rarely found in other habitats; *Cheilanthes sieberi* and *Pleurosorus rutifolius*, in particular, are found only in very dry habitats.

Coastal heathland. In this category are poorly drained coastal sites (mostly without free-running water) with no or very low shrub cover. This habitat is very common at the extreme northeast tip of Tasmania. Typical pteridophytes include *Selaginella uliginosa*, *Lindsaea linearis* and *Schizaea bifida*. Nine species of pteridophytes occur in this habitat (table 2); all except *Phylloglossum drummondii* and *Selaginella gracillima* frequently extend into bordering dry sclerophyll forest.

Wetland scrub. This habitat category comprises permanently wet, poorly drained sites (often with free-running water) at low altitudes that are exposed or semi-exposed with only a light scrub or sparse tree cover. Five fern species predominantly occur in this habitat (which is common in northeast Tasmania): *Blechnum minus*, *Gleichenia dicarpa*, *G. microphylla*, *Hypolepis muelleri* and *Todea barbara*. None of the five species is confined to this habitat.

Alpine. This broadly defined habitat embraces various non-aquatic habitats occurring mostly above 800 m, including rock outcrops, boulder fields, bogs, heathlands, herbfields and low scrub. Nine species are typical of this habitat (table 2), including *Grammitis poeppigiana* and *Lycopodium scariosum*. All nine species are restricted to this habitat in the Northeast, except for *Blechnum penna-marina* which frequently extends below 800 m.

Aquatic. Rivers, streams, lakes and swamps and their seasonally inundated margins make up the fully aquatic habitat. Pteridophytes here may be free-floating (e.g. *Azolla filiculoides*) or rooted in soil and submerged for at least part of the year (e.g. *Isoetes gunnii*). A total of five species (the two above, plus *I. drummondii*, *I. elatior* and *I. muelleri*) occur in aquatic habitats in northeast Tasmania. All are restricted to this habitat except *I. drummondii*, which may occur in roadside ditches and seasonally inundated grassland.

Littoral. The last habitat category comprises coastal cliffs

or rock outcrops and other coastal rocky sites not far above the high-water mark. *Asplenium obtusatum* is the only fern found mainly in this habitat, though some forest ferns (most notably *Phymatosorus pustulatus* and *Rumohra adiantiformis*) may occasionally occur here.

Conservation

The majority of pteridophyte species occurring in the Northeast are either well-reserved or not under any immediate threat within Tasmania. This is certainly the case with the 35 species occurring in wet forest. The list of species found in fern gullies usually mirrors that found in other wet forest types (i.e. rainforest and wet sclerophyll forest), and these fern gullies are often in terrain unsuitable for uses such as forestry, agriculture or residential settlement. However, the status of pteridophytes from other fern habitats more susceptible to human modification is not as clear. *Blechnum cartilagineum* and *Doodia caudata* from dry forest are possibly extinct in northeast Tasmania; the semi-aquatic *Isoetes drummondii* as well as *Schizaea asperula* from coastal heathland may also be extinct; and *Hypolepis muelleri* from wetland scrub and *Phylloglossum drummondii* and *Selaginella gracillima* from coastal heathland are all endangered. Details of the conservation status of these and other species are given below.

Blechnum cartilagineum was collected from Georges Bay in 1882 and 1893 but has rarely been seen in the Northeast since. In the 1980s, several sickly specimens of the fern were found growing on a disused vehicular track beside Constable Creek in the Georges Bay area, but it is feared these plants may no longer be extant (D. Ziegeler, pers. comm.). In 1981, a much larger and healthier colony was discovered west of Ansons Bay but the area has since been clearfelled. *B. cartilagineum* is a hardy species (Jones & Clemesha 1981, Duncan & Isaac 1986) and it is quite possible its rootstock may have survived this disturbance, but several subsequent attempts at locating the colony have failed. *B. cartilagineum* is rare in Tasmania, and extant populations are known only from south of Four Mile Creek and near Penguin. Plants at these sites grow on lightly forested creekside flats or on the lightly forested adjoining slopes.

Doodia caudata, *Isoetes drummondii* and *Schizaea asperula* have each been collected only once in northeast Tasmania: *D. caudata* from Georges Bay in 1891, *I. drummondii* from near George Town in 1955 and *S. asperula* from George Town in 1880. Recent repeated searching by the author has failed to locate *D. caudata* in the Georges Bay district. Existing available habitats in the area show little resemblance to those on the banks of the River Leven on the Central North Coast, the only known site of extant populations of the species in Tasmania. *I. drummondii* is uncommon in Tasmania; it has been found growing in shallow, still waters and their margins, frequently in man-made water channels (Garrett & Kantvilas 1992). The 1955 Northeast collection was from

a ditch on the side of the road to the aerodrome near George Town. *I. drummondii* can easily go unnoticed when growing amongst grasses, and it is quite possible the species still occurs at this site, as well as elsewhere in the Northeast. *Schizaea asperula* has been variously regarded by different authors as either a good species (e.g. Duncan & Isaac 1986) or as merely a form of *S. bifida* (e.g. Chinnock 1986). The present author formerly held the latter view, until plants with characteristics of *S. asperula* were found growing alongside *S. bifida* sens. strict. near Bicheno. Subsequent field studies have further convinced the author of the specific status of *S. asperula*. The Bicheno site is the only known location of extant populations of the species in Tasmania, and the present status of the George Town plants is unknown. Plants at Bicheno are growing in sandy soil under bracken in dry sclerophyll forest, while early collections from possibly extinct populations elsewhere in the State (concentrated in the Kingston/Blackmans Bay area) were from coastal heathland, as are Victorian populations (Duncan & Isaac 1986).

Hypolepis muelleri is uncommon and grows on moist alluvial flats or swamp margins, and its habitat is under threat from forestry operations and clearing of land for agriculture. *Phylloglossum drummondii* and *Selaginella gracillima* are also uncommon and both grow on flat and open heathland desirable for agriculture or residential development.

Isoetes elatior, *I. drummondii*, *Schizaea asperula* and the subspecies *Asplenium trichomanes* subsp. *trichomanes* are unreserved in Tasmania (Garrett, in press). *Isoetes elatior* is a Tasmanian endemic, and occurs in some medium to fast-flowing sections of the South Esk and Break O'Day Rivers where these run through privately owned land. Riverbank reservation only would seem inadequate, as upstream activities are just as crucial to the survival of this aquatic species. *Asplenium trichomanes* subsp. *trichomanes* occurs in State forest, where it grows on two dolerite outcrops on the Nicholas Range. One colony is adjacent to a *Pinus radiata* plantation while the other is under no immediate threat. The only other known Tasmanian population of this subspecies is nearby on Fingal Tier where it is under threat from quarryworks (Garrett 1995).

The whereabouts of extant populations of *Isoetes drummondii* and *Schizaea asperula* in northeast Tasmania are unknown.

Botrychium lunaria, *Hypolepis muelleri*, *Pellaea calidirupium*, *Pleurosorus rutifolius* and *Selaginella gracillima* are all poorly reserved in Tasmania (Garrett, in press). *Hypolepis muelleri* is not known from any mainland Tasmanian reserve and northeast Tasmania contains some of the largest known colonies of the species in the State. For example, a population occurs for several kilometres beside the Great Forester River and a smaller colony still exists at Tin Hut Creek west of

Ansons Bay in the vicinity of the lost colony of *Blechnum cartilagineum*. Both sites are in State forest. *Selaginella gracillima* is reserved only within Mt William National Park, but other populations exist along the northern coastline between Cape Portland and Bridport.

Botrychium lunaria, *Pellaea calidirupium* and *Pleurosorus rutifolius* reach their greatest abundance outside of northeast Tasmania. However, the sole Tasmanian reserve containing *P. rutifolius*, St Marys Pass State Reserve, is on the margin of the Northeast; only a handful of plants on a solitary rock outcrop are known from this location. The sole reserves containing *B. lunaria* and *P. calidirupium* are the Central Plateau part of the World Heritage Area and the Douglas-Apsley National Park respectively. Within the Northeast, each of the two species is known from single locations only: *B. lunaria* from Diddleum Plains and *P. calidirupium* from the Nicholas Range.

Acknowledgements

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The Coastal Vegetation of Northeast Tasmania

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Abstract

The Northeast has 260 km of coast. The coastal plant communities contain at least 227 vascular plant taxa or slightly over 30% of the total Tasmanian coastal flora of 770 species. Thirty-four coastal plant communities have been identified in the region, out of 62 plant communities recorded in a statewide survey. Most are well reserved. Secure reservation of Waterhouse Point would ensure that all were well-reserved. Percentage of organic matter in the soil, soil texture and exposure, as reflected in percentages of bare sand and bare rock, are important factors in differentiating this vegetation. Patterns of distribution of coastal species are presented in a State context.

Introduction

The coast of the Northeast extends 260 km from Four Mile Creek in the east to Low Head in the west. There are 160 km (61%) of sandy coast while the remainder (39%) is rocky coast. Muddy shore and estuarine mouth coasts are negligible. Statewide, 68% of coast is sandy and 29% rocky (the balance is mud and estuary mouth). Nationally 47% is sandy and 18% rocky (muddy shores and coral shores constitute most of the rest) (Fairweather 1990).

The climate on the coast is moist subhumid warm (Gentilli 1972) except for a belt of dry subhumid warm between Waterhouse Point and Musselroe Bay and an area of humid warm on the Bay of Fires. Rainfall ranges from less than 600 mm at Waterhouse Point, Cape Portland and Double Sandy Point (no station figures) to 782 mm at Bridport. Temperatures are mild (table 1).

Statewide studies have covered several elements of the coastal and near-coastal vegetation of the Northeast: dry coastal vegetation (Kirkpatrick & Harris 1995); saltmarsh (Kirkpatrick & Glasby 1981); heath (Kirkpatrick 1977) and enclosed wetlands (Kirkpatrick & Harwood 1983a, 1983b). In addition, there have been several papers reporting on the vegetation of parts of the coastal Northeast (Stephens & Cane 1938; Kirkpatrick & Wells 1987; Cameron, this volume). In the present paper we confine ourselves to the characteristics, ecology, biogeography and conservation of the dry coastal vascular plant flora and vegetation of the Northeast.

Methods

The present paper is based on data collected in the Northeast as part of a statewide survey of dry coastal vegetation (Kirkpatrick & Harris 1995). The aim of this quadrat sampling programme was to encompass the variation in dry coastal vegetation in each 10 x 10 km square of the National Mapping Grid in Tasmania. In any particular grid square there would usually be only one sample of any type of vegetation that seemed distinct to the sampler. A few grid squares were missed because of access problems, but, in these cases, nearby grid squares covered the same broad range of environmental conditions. Sampling took place between 1989 and 1993 and occurred at many different times of the year. Data were collected by Fiona Coates, Georgina Davis, Rod Fensham, Stephen Harris, Jamie Kirkpatrick, Tony Moscal, Alasdair Wells and Penny Wells.

Table 1. Some climatic data from coastal stations in the Northeast (Bureau of Meteorology 1975).

Station	1	2	3	4
Bridport	783	138	4.4 (July)-13.4 (Feb)	13.5 (July)-22.9 (Feb)
Eddystone	778	163	6.7 (July)-13.8 (Feb)	12.7 (July)-20.9 (Feb)
Low Head	681	145	6.0 (July)-13.5 (Feb)	12.1 (July)-21.3 (Feb)
St Helens	782	147	2.5 (July)-11.6 (Feb)	13.4 (July)-22.7 (Feb)

1 = mean annual rainfall (mm); 2 = number of raindays; 3 = mean daily minimum temperature range (^{O}C); 4 = mean daily maximum temperature range (^{O}C).

Sites were selected subjectively to include the least degraded examples of vegetation types that were perceptibly different to the sampler. Sampling took place by means of 1 x 10 m quadrats, with the long axis laid parallel to the coast. The presence of all vascular plant species visible at the time of sampling was noted for each quadrat and a supplementary list made of species that occurred in the same perceptible vegetation type, but not in the quadrat. Notes were made of the height and cover of all strata and of the dominant species, as indicated by cover, in the tallest stratum. A species was regarded as codominant if its cover was more than half of that of the most abundant species. The percentage cover of each lifeform (mosses, lichen, trees, shrubs, herbs, succulents, grasses, graminoids and ferns) was estimated for the quadrat as a whole. The following environmental data were also assembled or recorded for each quadrat:

1) location by six-figure grid reference and 10 x 10 km grid square;

2) land tenure (secure reserve (see below), other State-managed reserve with nature conservation as one management aim, other reserve (local government or State); non-allocated State Crown Land; Forestry Tasmania land; Commonwealth land; private Wildlife Sanctuary; private land);

3) site description (foredune/sandspit, partly stable dune, stable dune, single beach, rocky shore, low to medium headland, cliff, clifftop, laterite ledge);

4) aspect code (northwest = 1, north and west = 2, northeast and southwest = 3, south and east = 4, southeast = 5);

5) slope;

6) drainage (medium, good, sharp);

7) mean annual precipitation, derived from BIOCLIM (Busby 1986);

8) mean annual temperature, derived from BIOCLIM;

9) distance from the high-tide level;

10) fetch to east, north, south and west;

11) geology (basalt, dolerite, mudstone, granite, sandstone, greywacke, quartzwacke, quartzite, limestone, laterite, sand);

12) the estimated percentage cover of burrows;

13) the estimated percentage cover of bare ground;

14) the estimated percentage cover of sand;

15) the estimated percentage cover of bare rock;

16) the estimated percentage cover of shells;

17) the estimated percentage cover of litter;

18) the estimated percentage cover of disturbed ground;

19) type of disturbance (trampling, grazing by native birds and mammals, grazing by stock, grazing by rabbits, recently burnt, vehicle damage, organic rubbish, inorganic rubbish, drainage channels, nesting muttonbirds, nesting other birds);

20) dune mobility (active foredune, vegetated foredune, stable other dunes, unstable other dunes);

21) soil depth;

22) soil texture class;

23) calcium carbonate content of the surface 5 cm of soil;

24) loss on ignition of the surface 5 cm of soil;

25 conductivity of the surface 5 cm of soil; and

26) pH of the surface 5 cm of soil.

The quadrat presence/absence data for all taxa recorded in the 119 quadrats in northeast Tasmania were arranged in sorted tables, using the polythetic divisive computer programme TWINSPAN (Hill 1979) for initial sorting. These tables (appendices 1-3) are presented to give an indication of the nature of floristic variation in the region. We also list the floristic and dominance communities described from the region by Kirkpatrick and Harris (1995). These communities were selected from statewide sorted tables on the basis that they were recognizable, at least in their cores, through their combination of species. The dominance communities of Kirkpatrick and Harris (1995) were defined by the species most common in the tallest stratum with more than 10% cover.

The northeast Tasmanian floristic data were ordinated in two dimensions using the default options in DECODA (Minchin 1986) for non-metric multidimensional scaling. The floristic distances between quadrats were calculated using the Bray-Curtis coefficient. The vector-fitting option in DECODA was used to assess the environmental correlates of the two-dimensional ordination space. All continuous environmental and vegetation variables were used in this analysis.

The statewide conservation status of communities was assessed by reference to their occurrence in secure reserves, that is, reserves that require the permission of both Houses of the Tasmanian Parliament for their revocation, or which are protected under the World Heritage Convention. A community was assumed to be well-reserved if it occurred in several locations within one secure reserve or in two or more reserves, unless its locations in the reserves were threatened by ongoing processes. It was considered poorly-reserved if it was only found in one local area of one secure reserve.

Distribution maps of obligate and preferential coastal species were derived from TASPAWS, the Wildlife Atlas of the Parks and Wildlife Service. The data for these maps were mostly from the dry coastal vegetation survey but were supplemented by records from other data sets, notably that of Harris and Buchanan (1994).

Results and discussion

The flora

One hundred and sixty-two dicotyledons, 64 monocotyledons and one pteridophyte, 227 vascular taxa in all, were recorded from the quadrats in dry coastal

vegetation in the Northeast (appendix 4). Eight species that are rare in Tasmania were identified in the coastal data set (table 2). There were no nationally rare species.

Species distribution patterns

Table 2. Rare (Flora Advisory Committee 1994) dry coastal vascular plant species recorded from the Northeast.

Calocephalus lacteus	r2	Asteraceae
Cymbonotus lawsonianus	r2	Asteraceae
Eutaxia microphylla	r2	Fabaceae
Lasiopetalum baueri	r2	Sterculiaceae
Pomaderris paniculosa	r2u	Rhamnaceae
Sporobolus virginicus	r2	Poaceae
Stellaria multiflora	r2	Caryophyllaceae
Zieria veronicea	r2	Rutaceae

r2 = present in less than 20 national mapping grid squares (10 km) in Tasmania.
u = not known from a secure reserve.

The dry coasts of the Northeast support only two obligately coastal Tasmanian endemic vascular plant species (appendix 4). This low number is understandable given that the coastal environment of the Northeast is more similar to that of the southeast Australian mainland than that of other regions of Tasmania.

The native obligate or preferential coastal species of Tasmania appear to exhibit seven distinct patterns of distribution: 1) western, 2) southeastern, 3) eastern fragmentary, 4) northern tochold, 5) northeastern toehold, 6) Furneaux limit, and 7) widespread (fig. 1). This typology is subjective. We propose to test it quantitatively in a later paper. However, in this paper we present a brief discussion of the types that occur in the Northeast.

The majority of native obligate or preferential coastal species in the Northeast are widespread in Tasmania. Species in the western, southeastern and the Furneaux limit groups do not occur in the Northeast. The eastern fragmentary group consists of species which have disjunct distributions on the Tasmanian east coast, the Furneaux group and the Australian mainland. Coastal species exhibiting this distribution pattern include *Zieria cytisoides*, *Bulbine glauca* and *Eutaxia microphylla*. *Zieria veronicea*, which is confined in Tasmania to the Northeast, and *Leptospermum laevigatum*, found in the far Northeast and far Northwest, are respective examples of northeastern and northern tochold species. These toehold species may, in some cases, be recent migrants, yet to fully expand their ranges. For example, *Leptospermum laevigatum* is naturalized in southeast Tasmania. Alternatively, many may have their environmental limits in north Tasmania, their patchy distributions being a product of patterns of southward migration as Bass Strait filled with water in post-glacial times.

Plant communities

The major division in dry coastal vegetation in the Northeast is between predominantly grassy quadrats on sandy areas subject to disturbance (appendices 1 and 2) and other sites mainly on rocky shores, fertile soils or older sands with established vegetation (appendix 3). Beach and unstable foredune data are shown in appendix 1. The *Cakile* spp. and *Euphorbia paralias*, all introduced, form the seaward extreme. The native sand-binding grasses, *Austrofestuca littoralis* and *Spinifex sericeus*, become characteristic further inland. The shrub-dominated dune vegetation that occurs inland of the beach and unstable foredune vegetation forms several distinct species/quadrat groups in the second sorted table (appendix 2). The quadrats at the right of the table have more open vegetation, rich in small herbs, this openness usually resulting from human disturbance. In the sorted table in appendix 3 one distinctive group comprises a number of samples, largely recorded from rocky granite

Fig. 1. *Euphorbia paralias* invading a native grassland or marsupial lawn at Waterhouse. Observe the seedlings from the older *Euphorbia* plants at left. The scrub in the background is a mixture of mallee-form *Eucalyptus amygdalina*, *Acacia sophorae*, *Leucopogon parviflorus*, *Melaleuca* sp., and *Allocasuarina verticillata*.

Fig. 2. *Melaleuca squarrosa* and *Allocasuarina verticillata* (right) with dense mats of *Tetragonia implexicoma* in the understorey.

Western

Eastern Fragmentary

Furneaux Limit

Northern Toehold

Southeastern

Northeastern Toehold

Fig. 3. Major distribution patterns in obligate and preferential coastal species in Tasmania. Widespread coastal taxa showing no pattern at this level form a separate group.

or dolerite shores, where there are relatively poorly drained herb-filled crevices with species like *Lobelia alata*, *Samolus repens*, *Apium prostratum*, and *Selliera radicans* (fig. 2), occasionally with small seedlings or shrubs of *Melaleuca ericifolia*, and others with tussocks of *Stipa stipoides*. This table also includes heath, scrub and forest quadrats, with a distinct floristic break between those containing *Pteridium esculentum* and *Banksia marginata* and those containing *Correa alba* and *Muehlenbeckia adpressa*. This vegetation is transitional to the inland coastal heath and scrub.

Thirty-four of the 62 dry coastal plant communities recognized by Kirkpatrick and Harris (1995) were recorded from the Northeast. These are:

Dominance Communities

Stipa stipoides tussock grassland
Spinifex sericeus grassland
Schoenus nitens sedgeland
Poa poiformis tussock grassland
Olearia axillaris shrubland
Myoporum insulare shrubland
Melaleuca ericifolia heath/scrub
Leucopogon parviflorus shrubland
Lepidosperma gladiatum sedgeland
Isolepis nodosa sedgeland
Ozothamnus turbinatus shrubland
Correa alba heath
Carpobrotus rossii succulent herbfield
Leucophyta brownii shrubland
Banksia marginata heath scrub
Austrofestuca littoralis grassland
Alyxia buxifolia heath
Allocasuarina verticillata shrubland/low forest
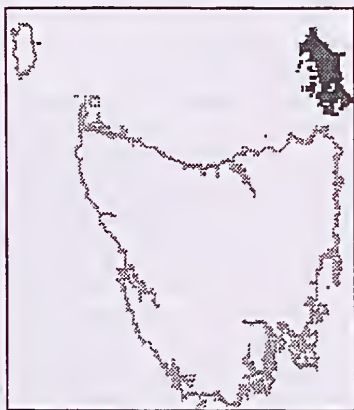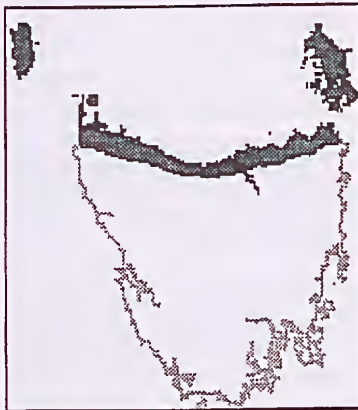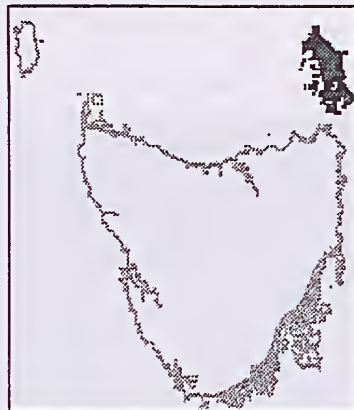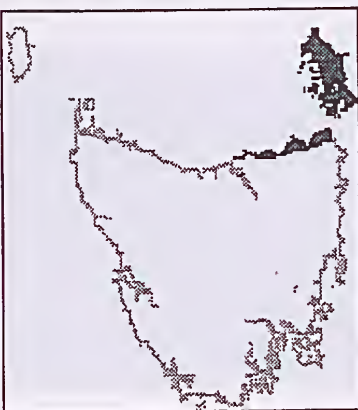*Acacia sophorae* heath/scrub

Floristic Communities

Leucopogon parviflorus-Lobelia alata-Isolepis nodosa shrubland
Leucopogon parviflorus-Acaena novae-zelandiae-Carpobrotus rossii shrubland
Samolus repens-Schoenus nitens herbland
Leucopogon parviflorus-Viola hederacea-Stipa flavescens shrubland
Leucopogon parviflorus-Lomandra longifolia-Pteridium esculentum shrubland
Leucopogon parviflorus-Lepidosperma concavum-Oxalis perennans heath
Banksia marginata-Leucopogon parviflorus-Pteridium esculentum heath/scrub
Stipa stipoides-Leucopogon parviflorus tussock grassland
Poa poiformis-Stipa stipoides-Dichondra repens tussock grassland
Stipa stipoides-Disphyma crassifolium tussock grassland
Rhagodia candolleana-Tetragonia implexicoma succulent herbland
Leucopogon parviflorus-Rhagodia candolleana shrubland
Spinifex sericeus-Leucopogon parviflorus grassland/shrubland
Acacia sophorae-Ozothamnus turbinatus shrubland
Spinifex sericeus-Austrofestuca littoralis grassland.

Correlates of floristic variation

The environmental variables that formed significant vectors in the floristically-defined ordination space were % bare sand (max. R = 0.6161, P = 0.000), % bare rock (max. R = 0.4062, P = 0.000), % litter (max R = 0.4352, P = 0.000), % organic matter (max. R = 0.4226, P = 0.000), soil texture (max. R = 0.5374, P = 0.000), pH

(max. R = 0.4474, P = 0.000), conductivity (max. R = 0.3446, P = 0.000), mean annual temperature (max. R = 0.2864, P = 0.020), mean minimum temperature of the coolest month (max. R = 0.2644, P = 0.000), mean temperature of the coolest quarter (max. R = 0.2568, P = 0.040), mean temperature of the warmest quarter (max. R

Fig. 4. Significant vectors in the two dimensional floristic ordination space. The length of the vector is directly related to its strength.

= 0.2476, P = 0.030) (fig. 4). The height of the dominant stratum (max. R = 0.3885, P = 0.000), the cover of the dominant stratum (max. R = 0.2595, P = 0.010) % tree cover (max. R = 0.2991, P = 0.000), % shrub cover (max. R = 0.5124, P = 0.000), % grass cover (max. R = 0.3436, P = 0.010), % graminoid cover (max. R = 0.3822, P = 0.000), % herb cover (max. R = 0.5011, P = 0.000) and % fern cover (max. R = 0.2900, P = 0.020) also formed significant vectors, indicating codirectionality of structural/dominance and floristic variation.

Weeds

Weeds are likely to be the most serious threat to the naturalness of the dry coastal vegetation of the Northeast. The coast is an environment characterised by natural disturbance and is therefore susceptible to exotic species invasion. Some species have already had an impact on the coast while others are currently extending their ranges. *Cakile edentula* and *C. maritima* are ubiquitous annuals which occur on beach berms, but the degree to which these species displace native species is uncertain. Marram grass (*Ammophila arenaria*) has been introduced on large areas of unstable coastal dune on the north coast. It is common on sandy coasts and appears to largely displace the natives *Austrofestuca littoralis* and *Spinifex sericeus*. It has been the most practical plant to use for stabilising sand sheets as there has been some difficulty in establishing *Spinifex sericeus* (D. Steane, pers. comm.;

Maze & Whalley 1992). It may be that *Spinifex* is close to its climatic limit in Tasmania, which may inhibit its fecundity. In New South Wales and Queensland it has been one of the common grasses used in sand dune stabilization.

Euphorbia paralias (European sea spurge) has spread from southern Australia (Kloot 1987) into the Furneaux Group and is now firmly established on the northeast Tasmanian coast, sometimes forming dense belts on the berm. Willis (1953) found it to be well-established amongst driftwood and clumps of *Isolepis nodosa* at only one location in the Recherche Archipelago in Western Australia, and noted that he knew of only one other location, on the west coast of Yorke Peninsula, South Australia. Heyligers (1985) mapped its subsequent spread along the coasts of southeast Australia. The invasion of Tasmanian shores by *E. paralias* probably began as recently as the 1980s. The species was first noticed as a few individuals on Deal Island in 1988 (Harris & Davis 1995), and has since expanded into a dense infestation. *E. paralias* now occurs along most parts of the north coast of Tasmania and is spreading down the west coast. It is pernicious because it has a very stout woody rootstock and is difficult to pull out once it becomes established. It seeds prolifically in late autumn and early winter. It has been observed aggressively invading a native herbfield and grassland above high water mark near Waterhouse Point and it appears easily capable of completely overwhelming such special habitats (fig. 2).

An understanding of the spread of *Euphorbia*, other weeds and certain native species onto the Tasmanian coast from sources further north is helped by examining the pattern of local sea currents and, in particular, the East Australian Current (Church & Cresswell 1986). The main location of the thermal front which separates Bass Strait water (to the west of the front) from the East Australian Current water (to the east) in winter follows the 200 m

isobath, but in summer may be 100 km further offshore, to the east of Tasmania. However there are occasions in summer when East Australian Current water sweeps westward into Bass Strait (fig. 5). This current provides a means of dispersal for some seeds or plant material fragments which may then establish on islands in Eastern Bass Strait, and, perhaps, the northeastern extremity of mainland Tasmania. Disseminules of tropical species, including *Cocos uncifera* and *Panginu edule*, have been found on the beaches of the Furneaux Group, probably resulting from southward transport in summer by the East Australian Current. The far northeastern extremities of the Northeast are likely capture points for propagules drifting eastward on the winter currents. Heyligers (1985) suggested that *Euphorbia paralias* may have arrived in this manner, given that its seeds remain viable after many weeks afloat. Some native plants may be spreading further south. *Frankenia pauciflora* (sea heath) represents a small group of plants which may have migrated on the winter currents; it presently occurs on the shores of a small number of islands in the southern Furneaux Group. Although this species is of Eremean origin and may be at its climatic limit, it could conceivably spread to, and persist upon the northeast Tasmanian coast. Once species establish on a Northeast beach, their further spread may result from more local water movements, such as longshore drift.

Many exotic species that have no adaptations for dispersal by sea are transported by birds, mammals and wind from settlements and farmland into the coastal vegetation of the Northeast. Among the shrub species that could potentially displace natives in dune and cliff vegetation, *Chrysanthemoides monilifera* (boneseed) and *Coprosma repens* (mirror bush) presently occur around holiday settlements. Forty-two exotic species, including only one shrub (*Coprosma repens*), were recorded within the quadrats (appendix 4), which were placed to avoid the worst areas of exotic infestation. Many of the species recorded in the quadrats are very common weeds, and

Fig. 5. Drift of surface waters on the basis of drift bottle recoveries (from Church & Cresswell 1987).

most also occur in habitats away from the coast. Some of the species are described as either cosmopolitan or 'probably introduced' in various Australian regional floras. They include *Plantago coronopus*, *Spergularia media* and *Polycarpon tetraphyllum*.

Reservation status of plant communities

Three of the dry coastal plant communities that occur in the Northeast have a poor reservation status on a statewide basis (Kirkpatrick & Harris 1995):

1) *Leucopogon parviflorus-Lepidosperma concavum-Oxalis perennans* heath;

2) *Melaleuca ericifolia* heath/scrub (this community is particularly significant for lichens (Dr G. Kantvilas, pers. comm.) as there are a number of distinctive taxa which apparently occur in Tasmania only in coastal *Melaleuca ericifolia* forest and scrub); and

3) *Olearia axillaris* shrubland.

All of these three communities occur in the Waterhouse Point Protected Area. Thus, a change in status of this area to a secure reserve would render all communities well-reserved.

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Appendix 1. Sorted table for quadrats on coastal foredunes. Species occurring in less than 2 quadrats have been omitted. * = exotic species; + = predominantly coastal species.

	Species	Quadrats
	Acaeno novae-zelandiae	- 1 1 - - 1 - - - - - - - - - - - - - -
+	*Acacia sophorae*	- 1 - 1 1 1 - - - - - - - - - - - - - -
*	*Picris hierocioides*	- - - 1 1 1 - - - - - - - - - - - - -
*	*Hypochaeris radicata*	- 1 - - 1 - - - - - 1 - - - - - - - -
+	*Isolepis nodosus*	- 1 - - - - - - - - - - 1 1 1 - - - -
+	*Actites megalocorpus*	- 1 - 1 1 1 1 1 - - 1 1 1 - - - - - -
+	*Austrofestuca littorolis*	1 1 1 1 1 1 1 1 1 - - 1 - 1 - - - -
*	*Sonchus oleraceus*	- 1 1 - 1 - - - - 1 1 1 1 1 - 1 - -
*	*Ammophila arenaria*	- 1 - - - 1 - 1 - 1 1 - - 1 - - - 1 -
+	*Spinifex sericeus*	1 - 1 1 1 1 1 - 1 1 1 1 1 1 1 1 1 - 1
+	*Apium prostratum*	1 - - - - - - - - - - - 1 - - - 1 -
*	*Cakile maritima*	1 1 1 - - - 1 1 - - - - - - - 1 1 1 -
*	*Euphorbia paralias*	- - - - - - 1 - - - 1 - - - - 1 - - 1
*	*Cakile edentula*	- - - - - - 1 1 1 - 1 - - - 1' - 1 1 1 -
+	*Ozothomuus turbinatus*	- 1 - - - 1 - - - - - - - - - - 1 - 1
+	*Tetrogonia implexicoma*	- - - - - - - - - - - - - - - - 1 1 - 1

Appendix 2. Sorted table for sand dunes inland from the sand-binding grassland. Species occurring in less than five quadrats have been omitted. * = exotic species; + = predominantly coastal species.

	Species	Data
*	*Ammophila arenaria*	- 1 - - - - - 1 1 1 1 1 1 1 - 1 - - - - - - - - - -
+	*Ozothamnus turbinatus*	1 1 - - - - - - - - - - - 1 1 1 - - 1 - - 1 - - - - - - 1 1 - - - 1 - - - - - - - - - - 1 - - - - - - - - - - 1
	Daucus glochidiatus	- - - - - - - - - - - 1 - - - - - - - - - - - 1 1 1 1 - - - - - - - - - - - - - - 1 - - - - - - - - - - - -
+	*Austrofestuca littor.*	- - - - 1 - - - - - - - - - - - - - - 1 - - 1 1 - - - - - 1 -
+	*Spinifex sericens*	- 1 - 1 - - - - - - - - - - 1 - 1 1 1 - 1 1 1 1 - 1 1 - - - 1 1 - 1 -
+	*Olearia axillaris*	1 - - - - - - - - - - - - - 1 - 1 1 - 1 1 1 - - 1 - 1 - 1 - - - - - 1 - - 1 - - 1 - - - - - - - - - - - - -
	Agrostis sp.	- 1 1 1 1 - - - 1 -
+	*Apium prostratum*	- - - - 1 1 1 - - - - - - - 1 1 - - - - - 1 - - 1 - - - - - 1 1 1 1 1 - - - - - - 1 - - - - - 1 1 1 1 1 - 1 - - - -
	Senecio biserratus	- - - - - 1 - - - - - - - 1 - - - - - 1 1 - 1 1 1 1 - - - 1 - 1 - - - - - - - 1 - - - - - - - 1 - 1 1 1 - - - - -
+	*Acacia sophorae*	- 1 - - 1 - 1 1 1 1 1 1 1 1 1 1 - 1 1 1 1 1 1 1 1 1 1 1 1 - - 1 - 1 1 1 - - - - 1 1 1 - 1 - 1 - 1 - - - 1 - 1 - 1
+	*Carpobrotus rossii*	1 1 1 1 1 1 1 1 - 1 1 1 - - 1 1 1 - 1 1 1 - - 1 - 1 1 - - - - - - - 1 1 1 - 1 1 - - 1 - - 1 1 - - 1 1 - - - -
+	*Actites megalocarpa*	1 1 - - 1 - 1 - - 1 1 1 - - 1 - 1 - 1 - 1 - 1 - - - - - - - 1 - - - - - - - 1 - - - - - - 1 - - - - - 1 - 1 1 - - - - - 1
+	*Isolepis nodosa*	1 - 1 1 1 - 1 - - 1 1 - - - - 1 1 - - - - 1 1 1 1 1 1 1 - - 1 - - 1 - - 1 - 1 - 1 1 - 1 - 1 - 1 - 1 1 - - - - - - 1 -
	Senecio lautus	- 1 - - - - 1 - - - - - - - - - - - 1 - 1 - - 1 - - -
*	*Sonchus oleraceus*	- - - - - - - 1 - - 1 - - - - - - 1 - 1 1 - - - - - 1 1 - - - - - - 1 - - - - - - - - - - 1 - 1 1 1 - 1 1 - -
	Oxalis perennans	- - 1 - - - - - 1 - - 1 1 - - - - - 1 1 1 1 1 - - 1 1 - - - 1 1 1 - 1 - 1 1 1 - - 1 1 - - 1 1 1 1 - 1 1 1
	Acaena novae-zelandiae	- 1 1 - 1 - - - - - 1 - - - - 1 - - 1 1 1 - - 1 1 1 - 1 - - - - - - - 1 - - - - - 1 1 1 - 1 - 1 - 1 - - - 1 1 1 - 1 1
	Galium australe	- - - - 1 1 - - - - - 1 - - - - - - - - - - - - - 1 - 1 1 1 1 1 1 - - - - 1 1 - - - - - - - 1 - - - - - -
*	*Picris heiracioides*	- - - - 1 - - 1 - - - 1 - 1 - 1 - - - - - - - - - - 1 - 1 - - - 1 - - - 1 - - 1 - - - 1 - - - 1 - - - - - -
+	*Rhagodia candolleana*	- - - - - - - 1 - - - - - - - - 1 1 1 1 1 - 1 1 - - 1 1 - - 1 1 1 1 - - 1 1 1 1 1 1 1 1 1 - - - - 1 - - - 1 1 1 - -
	Cotula reptans	- - - - - - - - - - - - - - - - - 1 1 1 - - - - - - - - - - - - - - - - 1 - - 1 - - - - 1 - - - - - - - -
	Senecio sp.2	- - - - - - - - - - 1 - - - - - - - - - 1 - 1 - - - - - - - - - 1 - - - - - - 1 1 - - - - - - -
	Clematis microphylla	- - - - 1 - - - - - - - - - - - - 1 - 1 - - - 1 - - - - - - 1 - - - - - 1 - 1 1 1 - - - - - - -
+	*Leucopogon parviflorus*	1 1 - - 1 - - 1 - - 1 - - - 1 - - - 1 - 1 1 - 1 1 1 - - 1 1 1 - - - - 1 1 - - 1 1 1 1 1 1 1 - 1 1 - 1 1 - 1 1 - 1 1 1 1 - 1
+	*Tetragonia implexicoma*	- - - - - - 1 - - - - - - - - - 1 - 1 1 - - - - - - - - 1 - 1 1 1 - 1 - - 1 1 1 1 1 - 1 1 1 - - - 1 1 1 1 - - - - -
	Calytrix tetragona	- 1 - - - - - - - - - - - - - - - 1 1 - - - - - - - - - - 1 1 - - - - - - - - 1 - - - - -
+	*Leucophyta brownii*	1 1 - 1 - 1 - - - - - - - - - 1 - 1 - 1 1 1 - 1 - - -
+	*Distichlis distichophylla*	- - 1 - - - - - - - - - - - - - - - - - 1 - - 1 - - - - - - - - - - - - - - - 1 - 1 1 1
*	*Hypochaeris radicata*	- - - - 1 1 - - 1 1 1 - - - - - - - - - - - - - - - - - 1 - - - - - - - - 1 - 1 1 - 1 - 1 1 1 - - 1 1 1 1 -
	Stipa flavescens	- - - - - - - - - - - 1 - - - - - - - 1 1 - 1 - 1 - - - 1 - - - - 1 1 1 1 - 1 1 1 1 1 - 1 1 - 1 1 - 1 1 1 1 1 - 1 - 1 - -
	Crassula sieberiana	1 - - - - - - - - - - - - - - - - - - 1 - - - - - - - - 1 - - 1 1 - 1 - - - - - - - 1 - - - 1 - - 1 - 1 1 1 -
	Dichondra repens	- - - - - - - - - - - - - - - - - - - 1 1 - 1 - - 1 - 1 - 1 1 - 1 - 1 - 1 1 1 1 1 1 - 1 - 1 1 1 1 1 1 - - 1 1
+	*Poa poiformis*	1 - - - - - - - - 1 - - - 1 - - - - 1 - - - - - - - - - - 1 1 - 1 1 - 1 - - - 1 1 1 - - 1 - 1 - 1 - - 1 -
+	*Muehlenbeckia adpressa*	1 - - - - - - 1 1 - 1 - - - - - - - - - 1 - - 1 - 1 1 - - - - - - - 1 1 - -
+	*Lepidosperma gladiatum*	- - - 1 - 1 - - 1 1 1 1 1 1 1 - - 1 1 - - 1 - - - 1 - - 1 1 1 1 -
	Lepidosperma concavum	- 1 - - 1 1 - 1 1 - - - - - - - - - - - - - - - 1 -
	Geranium potentilloides	- 1 1 1 1 1 - 1 - - - - - 1 - - 1 -
*	*Vicia sp.*	- 1 - - 1 1 - 1 - 1 - - - - - - - 1 -
*	*Lagurus ovatus*	- - - - - - - 1 - 1 1 - - - - 1 - 1 1 - - - 1 1 - -
*	*Anagallis arvensis*	- - - - - - - - - - - - - 1 - - - - - - - - 1 - - - - - - - - - 1 1 - 1 1 1 1 1 1 - - - - - 1 1 1 1 1 1 - - 1 - 1
+	*Pimelea serpyllifolia*	- 1 - - - - - - - - - 1 - 1 - 1 - - - - 1 -
+	*Stipa stipoides*	1 - - 1 - 1 - - - - 1 - - - - - - - - - 1 1 1 1 1 1 - 1
	Pimelea glauca	- - - - - - - - - - 1 - 1 - - - - 1 - - - - - 1 - - - - 1 - - 1 1 -
	Lomandra longifolia	- 1 - - - 1 - - - - - 1 - - 1 1 1 - -
	Dianella revoluta	- - - - - - - - - - - - - - 1 - 1 1 1 - - - - - - - - 1 1 - - - - - 1 1 1 1 1
*	*Trifolium sp.*	- 1 1 - - - - 1 1 1 1 - - - - - 1 -
*	*Plantago coronopus*	- 1 - 1 1 1 1 - - -

Appendix 3. Sorted table for rocky shore and more inland quadrats. Species occurring in less than five quadrats have been omitted. * = exotic species; + = predominantly coastal species.

```
    Acaena echinata          --------1-------1-----------11-----------
    Danthonia spp.           --------------1-----111-11111------------
    Brachyscome sp.          ---------------11-----1--1---------------
    Kennedia prostrata       -1--------------1-----1-----11-----------
    Senecio biserratus       -----1-1-------11--1--1-1---1-1----------
    Hibbertia sericea        ----11--1-----------1-1---1-11-----------
  + Zoysia macrantha         -----------1-11------------1-------------
    Aotus ericoides          -----11-1------------------11------------
  + Correa alba              -----------------11-11-1-1---------------
  + Muehlenbeckia adpressa   --11--------11--1-11--111----------------
    Gnaphalium involucratum  ----------------1111---------------------
    Allocasuarina verticill. -------11-1--------11--1-----------------
  * Vulpia bromoides         ---1-----------1--1---11-----------------
  * Aira carophyllea         11-1-------------1-1-----11--------------
  * Centaurium erythraea     -1--------------1-11---------------------
    Stipa flavescens         1-------1-1----11111--1--1---1-----------
  + Alyxia buxifolia         -----------1-----1-11---1-1--------------
    Dianella revoluta        1111-1----------11------11-1-------------
  * Anagallis arvensis       -------11----------1---1-1----1----------
    Hypoxis glabella         -----1-----1---------11----1-------------
    Correa reflexa           -111-1-----------------------------------
    Banksia marginata        111-111-1--1-11---1--------1-------------
    Bossiaea cinerea         -11111-----------------------------------
    Pteridium esculentum     1-1-11-111111111----11-1----------------
    Amperea xiphoclada       -111-1-----------------------------------
    Astroloma humifusum      11--1-----------1--------1---------------
    Acrotriche serrulata     --1-1---1--1-1-----1---1-----------------
    Lepidosperma concavum    11111111111-11-1----1-11--111------------
  + Acacia sophorae          1111111-1-11111-1-11--11--1-----------1-
    Oxalis perennans         -111-1111111-1111-1111111-1111---1-------
  + Poa poiformis            1111------------1111---------1----------1-
    Lomandra longifolia      11111111-1111---111111-111--1---1------1-
  + Leucopogon parviflorus   -1111--11-11111111111111--1-----1---1-1--
  * Sonchus oleraceus        -----1----1-----1--1----------1----------
  + Lepidosperma gladiatum   -----1-1-1-----11----------------------1-
  * Lagurus ovatus           --------1-1--------1-1-----------1----
    Melaleuca ericifolia     ----1--1-1--1------1-----1--------------11
  + Rhagodia candolleana     ----------1------1--1-11----11------1-1----
  * Hypochaeris radicata     -111-1-------1--1111-1-11---1---1-----1--
    Galium australe          -------------------1-111---1----1--------
  + Carpobrotus rossii       1111-----------1----111----1-11-1----1---
    Pimelea glauca           11--11----1----1-----------111--1--------
    Dichondra repens         1--1-1--1111----111--111--11--11-1-1-----
    Acianthus reniformis     ----11--------1-------1-----1----1-------
    Agrostis sp.             -----1-------------1------11--1----------
    Crassula sieberiana      ----------------1--1-11-11-1-11-1----1---
    Glossodia major          ---------------------1-----11---1--------
    Gnaphalium collinum      ------------- --1----------1-1-----1--------
    Vellereophyton dealbat.  ------------------1-1------1-1--------11---
  + Tetragonia implexicoma   ------------1----------1----------1-1----
  + Actites megalocarpa      ---1-----------------1---------11---11-1----
    Acaena novae-zelandiae   --------1-----------------1---1-1-------
  + Disphyma crassifolium    ---------------------------111-1---1----
  * Plantago coronopus       ----------------------------1--1-11111--111--
  + Stipa stipoides          ------------------------------1---1---11-11-1--
  + Distichlis distichoph.   ----------------------------1------1-11--11111---
  + Sarcocornia quinqueft.   ------------------------------------111--11--1
  + Samolus repens           ---------------------------------1111---11-1
  + Schoenus niteus          -------------1----1---------1--1111----1-1
  + Apium prostratum         -----1--------------1-------1----1---1111--1111
  + Selliera radicans        ----------1----------------------------1-1111111
  + Lobelia alata            ----------------1-------1---------1---------1111
  + Isolepis nodosa          1-11---------1--1-----1----------11--11-11-
  + Leptocarpus brownii      -1---------------------------1-----------1
```

Appendix 4. Species recorded in sample plots in northeast Tasmania during a systematic survey of Tasmanian coastal vegetation, July 1985-August 1993. Nomenclature follows Buchanan (1985). **i** = introduced species, **e** = Tasmanian endemic species, **c** = obligate or preferential coastal species.

DICOTYLEDONAE

AIZOACEAE
- c   *Carpobrotis rossii*
- c   *Disphyma crassifolium*
- c   *Tetragonia implexicoma*

APIACEAE
- c   *Apium prostratum*
-     *Daucus glochidiatus*
-     *Hydrocotyle hirta*
-     *Hydrocotyle muscosa*
-     *Hydrocotyle sibthorpioides*

APOCYNACEAE
- c   *Alyxia buxifolia*

ASTERACEAE
- c   *Actites megalocarpa*
- i   *Arctotheca calendula*
-     *Brachyscome decipiens*
-     *Brachyscome sp.*
-     *Calocephalus lacteus*
- i   *Cirsium vulgare*
-     *Chrysocephalum apiculatum*
-     *Chrysocephalum semipapposum*
-     *Cotula australis*
-     *Cymbonotus preissianus*
-     *Gnaphalium collinum*
-     *Gnaphalium indutum*
-     *Gnaphalium involucratum*
-     *Helichrysum scorpioides*
- i   *Hypochaeris glabra*
- i   *Hypochaeris radicata*
-     *Lagenifera stipitata*
-     *Leptinella longipes*
-     *Leptinella reptans*
- c   *Leucophyta brownii*
- c   *Olearia axillaris*
- c   *Olearia lepidophylla*
-     *Olearia ramulosa*
- c   *Ozothamnus gunnii*
- ce *Ozothamnus reticulatus*
- c   *Ozothamnus turbinatus*
- i   *Picris hieracioides*
-     *Senecio biserratus*
-     *Senecio lautus*
-     *Senecio sp. 2*
- i   *Sonchus asper*
- i   *Sonchus oleraceus*
-     *Vellereophyton dealbatum*

BRASSICACEAE
- i   *Cakile edentula*
- i   *Cakile maritima*
-     *Hymenobolus procumbens*

CAMPANULACEAE
- c   *Lobelia alata*
-     *Wahlenbergia gymnoclada*
-     *Wahlenbergia stricta*
-     *Wahlenbergia sp.*

CARYOPHYLLACEAE
- i   *Cerastium glomeratum*
-     *Colobanthus apetalus*
- i   *Sagina maritima*
- i   *Spergularia media*
- i   *Stellaria media*
-     *Stellaria multiflora*
- i   *Stellaria pallida*

CASUARINACEAE
-     *Allocasuarina littoralis*
-     *Allocasuarina monilifera*
-     *Allocasuarina verticillata*

CHENOPODIACEAE
- c   *Atriplex billardierei*
- c   *Atriplex cinerea*
- c   *Rhagodia candolleana*
-     *Sarcocornia quinqueflora*

CONVOLVULACEAE
-     *Dichondra repens*
- c   *Wilsonia backhousei*

CRASSULACEAE
-     *Crassula sieberiana*
-     *Crassula sp.*

DILLENIACEAE
-     *Hibbertia hirsuta*
-     *Hibbertia sericea*

EPACRIDACEAE
-     *Acrotriche serrulata*
-     *Astroloma humifusum*
-     *Epacris impressa*
-     *Leucopogon collinus*
-     *Leucopogon ericoides*
- c   *Leucopogon parviflorus*
-     *Leucopogon virgatus*
- c   *Monotoca elliptica*

EUPHORBIACEAE
-     *Amperea xiphoclada*
- ci *Euphorbia paralias*
-     *Phyllanthus gunnii*

FABACEAE
-     *Aotus ericoides*
-     *Bossiaea cinerea*
-     *Bossiaea cordigera*
-     *Dillwynia cinerascens*
-     *Eutaxia microphylla*
-     *Kennedia prostrata*
-     *Platylobium triangulare*
-     *Pultenaea daphnoides*
-     *Pultenaea tenuifolia*
- i   *Trifolium repens*
- i   *Trifolium sp.*
- i   *Vicia sp.*

FUMARIACEAE
- i   *Fumaria sp.*
- i   *Centaurium erythraea*

GERANIACEAE
-     *Geranium potentilloides*
-     *Geranium solanderi*
- i   *Geranium dissectum*
-     *Pelargonium australe*
-     *Pelargonium inodorum*

GOODENIACEAE
-     *Goodenia ovata*
-     *Selliera radicans*

HALORAGACEAE
-     *Gonocarpus teucrioides*
-     *Gonocarpus sp.*

LAMIACEAE
-     *Mentha diemenica*
- i   *Prunella vulgaris*

LAURACEAE
-     *Cassytha glabella*
-     *Cassytha pubescens*

LINACEAE
-     *Linum marginale*

MIMOSACEAE
-     *Acacia terminalis*
-     *Acacia genistifolia*
- c   *Acacia sophorae*
-     *Acacia suaveolens*
-     *Acacia verticillata* var. *verticillata*
-     *Acacia verticillata* var. *ovoidea*

MYOPORACEAE
- c   *Myoporum insulare*

MYRTACEAE
-     *Calytrix tetragona*
- c   *Leptospermum laevigatum*
-     *Leptospermum lanigerum*
-     *Leptospermum scoparium*
-     *Melaleuca ericifolia*
-     *Melaleuca gibbosa*
-     *Melaleuca squarrosa*

ONAGRACEAE
-     *Epilobium sp.*
-     *Epilobium billardierianum*

OXALIDACEAE
-     *Oxalis perennans*

PITTOSPORACEAE
-     *Pittosporum bicolor*

PLANTAGINACEAE
- i   *Plantago coronopus*
- ce *Plantago bellidioides*
-     *Plantago varia*
- i   *Plantago hispida*
- i   *Plantago lanceolata*

POLYGONACEAE
- c   *Muehlenbeckia adpressa*
-     *Rumex brownii*

POLYGALACEAE
-     *Comesperma volubile*

PORTULACACEAE
    Calandrinia calyptrata

PRIMULACEAE
i   *Anagallis arvensis*
c   *Samolus repens*

PROTEACEAE
    Banksia marginata

RANUNCULACEAE
    Clematis microphylla

RHAMNACEAE
    Pomaderris apetala
c   *Pomaderris paniculosa*
ROSACEAE
    Acaena echinata
    Acaena ovina
    Acaena sp.

RUBIACEAE
    Asperula conferta
ci *Coprosma repens*
    Galium australe
    Opercularia ovata
    Opercularia varia

RUTACEAE
c   *Correa alba*
    Correa reflexa

SANTALACEAE
    Exocarpos cupressiformis
    Leptomeria drupacea

SCROPHULARIACEAE
    Veronica gracilis

SOLONACEAE
    Solanum laciniatum
i   *Solanum nigrum*

STERCULIACEAE
c   *Lasiopetalum baueri*

THYMELEACEAE
    Pimelea glauca
c   *Pimelea serpyllifolia*
    Pimelea linifolia
    Pimelea humilis

VIOLACEAE
    Viola hederacea

MONOCOTYLEDONAE

CENTROLEPIDACEAE
    Centrolepis strigosa
    Centrolepis sp.

CYPERACEAE
    Baumea juncea
    Baumea tetragona
    Carex appressa
    Carex breviculmis
    Carex sp.
    Isolepis cernua
c   *Isolepis nodosa*
    Isolepis marginata
    Isolepis sp.
    Gahnia trifida
    Lepidosperma concavum
c   *Lepidosperma gladiatum*
    Lepidosperma laterale
    Schoenus maschalinus
    Schoenus nitens

IRIDACEAE
    Diplarrena moraea

JUNCACEAE
c   *Juncus krausii*
    Juncus planifolius
    Luzula sp.

LILIACEAE
    Bulbine glauca
    Bulbine semibarbata
    Dianella revoluta
    Hypoxis glabella
    Thysanotus patersonii

ORCHIDACEAE
    Acianthus reniformis
    Glossodia major

POACEAE
    Agrostis billardierei
    Agrostis sp.
i   *Aira caryophyllea*
i   *Aira praecox*
ci *Ammophila arenaria*
c   *Austrofestuca littoralis*
i   *Bromus hordeaceus*
i   *Bromus sterilis*
i   *Dactylis glomerata*
    Danthonia caespitosa
    Danthonia sp.
    Dichelachne crinita
c   *Distichlis distichophylla*
i   *Holcus lanatus*
i   *Hordeum murinum*
c   *Imperata cylindrica*
ci *Lagurus ovatus*
i   *Lolium perenne*
i   *Poa annua*
c   *Poa poiformis*
    Poa sp.
c   *Spinifex sericeus*
i   *Sporobolus indicus* var. *capensis*
c   *Sporobolus virginicus*
    Stipa flavescens
    Stipa mollis
c   *Stipa stipoides*
    Stipa stuposa
    Stipa sp.
    Themeda triandra
i   *Vulpia bromoides*
c   *Zoysia macrantha*

RESTIONACEAE
c   *Leptocarpus brownii*

STYLIDIACEAE
    Stylidium graminifolium

XANTHORRHOAEACEAE
    Lomandra longifolia

PTERIDOPHYTA

DENNSTAEDTIACEAE
    Pteridium esculentum

The Significance of Northeast Tasmania for the Biogeography of Endemic Australian Freshwater Algae

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Abstract

Coastal lagoons are part of the outstanding limnological richness of Tasmania. Those in the south harbour a number of endemic Australian species of very restricted distribution. Some of these are Australian 'flagship' taxa by virtue of their considerable novelty, beauty or intellectual appeal. Some coastal lagoons also house frail algae that are rare in the world, but not endemic to Australia. Of the coastal lagoons of northeast Tasmania only those at Stieglitz, near St Helens, have most of the endemic and rare species. However from Cape Naturaliste to Blackmans Lagoon some lagoons contain the endemic *Prorocentrum foveolata*, known elsewhere only from the mainland. In southern Tasmania its relative *P. playfairi* occurs; the difference is ecological, not latitudinal. Northeast lagoons also contain some algae common on the mainland but unknown elsewhere in Tasmania. The phycological significance of Northeast coastal lagoons, then, is as a biogeographical toehold for some mainland species and as a northern outpost of rare or endemic frail algae within Tasmania.

Introduction

Tasmanian coastal lagoons, principally in the south of the State, have been identified (Bowling et al. 1993) as sites of great biotic richness, harbouring some new and uniquely Australian microorganisms (Tyler 1992, Tyler & Wickham 1988), especially algae. Some of them are glamorous 'flagship' species (Tyler, in press). Some of these are also found in coastal lagoons on Fraser Island, Queensland (Croome & Tyler 1988a, Croome et al. 1988). Tyler (in press) is of the opinion that there are frail endemics that are confined to near-pristine waterbodies surrounded by native vegetation, and robust endemics that are less demanding. The frail endemics are mostly chrysophytes or dinoflagellates, such as *Dinobryon unguentariforme* (Croome et al. 1988), *Chrysonephele palustre* (Pipes et al. 1989) and *Thecadiniopsis tasmanica* (Croome et al. 1987). To all intents and purposes these are confined to coastal or upland lagoons, especially reed-grown ones, with dystrophic water, low salinity and low pH. Some such lagoons also house algae that are not endemic but are nonetheless rare; for most of these latter species there are no published records for Australia. Robust endemics, on the other hand, tolerate a wider range of water quality from oligotrophic to eutrophic. Examples are *Micrasterias hardyi* and *Tessellaria volvocina* (Tyler, in press). Of particular interest are two endemic species of *Prorocentrum* (Croome & Tyler 1987), a predominantly marine genus of dinoflagellates. One, *P. playfairi*, is a fragile endemic, the other, *P. foveolata*, is probably a robust endemic.

Limnological data for coastal lagoons of northeast Tasmania are given by Bowling et al. (1993), Buckney and Tyler (1973) and, in the context of conservation, by Kirkpatrick and Tyler (1987). Phycologically, the coastal lagoons of northeast Tasmania have been poorly studied.

No systematic, floristic study has been made of them. Nonetheless, they have been included in broader surveys (Bowling et al. 1993; Croome & Tyler 1985, 1988a, 1988b; Ling et al. 1989) and their attributes regarding the glamorous, 'flagship' taxa are known. They are of particular interest in the context of the biogeography of *Prorocentrum* and also some other endemic species. One lagoon has the novelty of harbouring a dinoflagellate common on the Australian mainland but unknown elsewhere in Tasmania.

Results

Formerly, both species of *Prorocentrum* were recorded from New South Wales and New Zealand (Playfair 1919, 1923; Croome & Tyler 1987). It is not known whether they still survive there. *P. playfairi* is widely distributed in Tasmania, always in water of low salinity (K_{25} <1000 µS cm-1) (Croome & Tyler 1987). There have been no records from mainland Australia since 1919. The only lagoons in northeast Tasmania where it is found are the three dystrophic ones (figs 1-3; K_{25} <1000 µS cm⁻¹) at Stieglitz, near St Helens, where some other frail endemics also occur, and on Flinders and Cape Barren Islands. *P. foveolata*, on the other hand, is not usually found in the low-salinity, dystrophic waters of southern lagoons. Initially (Croome & Tyler 1987) it was located in only two places, Little Waterhouse Lake and Blackmans Lagoon, but later (Ling et al. 1989) it was found in the Tregaron Lagoons. These have higher salinity (K_{25} = c. 1000-2500 µS cm⁻¹) and higher pH (>6.5) than dystrophic southern lagoons. Recently, *P. foveolata* has been located in lagoons at Cape Naturaliste, dystrophic lagoons of moderate salinity (K_{25} = c. 500-2800 µS cm⁻¹) and pH (4.4-7.5), in low-salinity lagoons near Stieglitz, where *P. playfairi* also occurs, and on Flinders Island. On the mainland it is known in Victoria from lagoons near

Peterborough (K_{25} = c. 900-1900 µS cm^{-1}; pH = 6.5-8.5) and from Tower Hill, near Warrnambool (K_{25} = c. 6.0-13.0 mS cm^{-1}; pH = ca. 9.0-9.4). The fragile endemic *Dinobryon unguentariforne* occurs in Windmill Lagoon, near Stieglitz. The dinoflagellate *Ceratium hirudinella* occurs widely on the Australian mainland but is known in Tasmania only from Big Waterhouse Lake (Ling et al. 1989).

Discussion

It is likely that, with the exception of those near Stieglitz, the salinity of lagoons in northeast Tasmania is too great for the frail endemics characteristic of southern Tasmania. All other northeast Tasmanian lagoons so far investigated have conductivity values indicating moderately brackish conditions (Bowling et al. 1993). The robust endemic *Prorocentrum foveolata* is confined, in Tasmania, to the northeast tip of the State, but then only in certain lagoons, and to some Bass Strait islands. Details of these recent finds will be presented elsewhere. The lack of *P. playfairi*, however, in northeast Tasmania (except St Helens) is not latitudinally related because the species formerly occurred in New South Wales (Playfair 1919) and still occurs on Cape Barren Island. *P. foveolata* has always been scarce in Blackmans Lagoon and Little Waterhouse Lake. On occasions we have been unable to find it there. There are no recent records from the Tregaron Lagoons. Blackmans Lagoon, over the years, has been subjected to artificial regulation of the water level and it seems that the best chance for the survival of this endemic species in mainland Tasmania lies within the lagoons at Cape Naturaliste, with the protection of Mt William National Park, and in the lagoons at Stieglitz, near St Helens.

Jocks, Windmill and Moriarty Lagoons at Stieglitz (figs 1-3) are of special value. They contain several of the frail endemics (Tyler, in press). Additionally they contain some uncommon algae that are also uncommon in other parts of the world. A thorough survey, in progress, is likely to reveal not only rarities but new species. The lagoons lie partly in a State Recreation Area. Special mention is made of Moriarty Lagoon; of the three it contains the richest diversity of endemic algal taxa and of other protistans, and hence is of greater value in terms of vicariance biogeography (Platnick 1992), yet is likely to be the least valued because it is a very shallow, reed-grown swamp, likely to dry up in many summers. Such sites must not be undervalued. Throughout the State they are the richest sites of rarity. One such is the only known locality for the intriguing *Chrysonephele palustris* (Pipes et al. 1989).

From the viewpoint of our limited phycological knowledge the biogeographical significance of coastal lagoons in northeast Tasmania is as northern outposts, especially at St Helens, of some frail 'flagship algae' and as toeholds of both endemic and cosmopolitan species common on the mainland but elsewhere absent in Tasmania. The Bass Strait Islands are stepping stones in some of these cases.

Acknowledgements

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Fig. 1. Jocks Lagoon, c. 3 km south of Stieglitz. The dense, emergent vegetation is *Eleocharis* sp., the floating macrophyte is *Triglochin* sp.

Fig. 2. Windmill Lagoon, near Stieglitz, showing emergent stands of *Eleocharis* sp. and lower tufts of *Triglochin* sp.

Fig. 3. Moriarty Lagoon (= Moriarty Swamp) at its northern end. In April 1996 there was c. 25 cm of water in the depression (left centre); the rest was virtually dry.

Zoology

The Frogs of Northeast Tasmania

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Abstract

Frog distribution in northeast Tasmania is better understood following a statewide frog survey undertaken from 1992 to 1994 in which almost 5 000 records were examined. The status of nine species of frogs known to occur in the region is examined. Northeast Tasmania is a significant region in a frog context and is the stronghold of *Litoria raniformis*, a species classified as 'vulnerable' in the State. Important frog habitats are identified, particularly the coastal wetlands. Current and projected threats to frog populations in the region such as drainage of wetlands are identified.

Introduction

Eleven species of frogs occur in Tasmania. They comprise a very small percentage of the approximately 250 species occurring on the Australian continent. Much of Tasmania is well suited to frogs with most parts receiving predictable annual rainfall. In the drier areas, including parts of the Northeast, rains are often extremely heavy and lead to substantial flooding of plains adjacent to rivers. These flooded plains form outstanding frog habitats, often used for mass breeding, in lagoons and temporary wetlands left by the receding floodwaters. Brook (1979) and Martin and Littlejohn (1982) mapped known distributions of Tasmanian frogs summarising historical and then current data, including that which related to the Northeast, but the only studies undertaken in the region specifically related to frogs have been in the sclerophyll forests near Old Chum Dam (Taylor & Dudley 1993), in Mt William National Park (D. Rounsevell, pers. comm.) and in the Waterhouse area (Brown, in press). This paper presents results from a recent statewide study of frog distributions.

A new frog atlas

Between November 1992 and July 1994 the Tasmanian Parks and Wildlife Service carried out a project to update the atlases prepared by Brook (1979) and by Martin and Littlejohn (1982). In gathering data for a new atlas, a broad range of people from across the community contributed records, including members of field naturalist clubs, school staff and students, Parks and Wildlife field staff and a number of frog enthusiasts. A total of 4 800 records were collected, mainly during daylight hours, in the survey. Those parts of Tasmania where coverage was least complete were the Southwest and a few small areas in the Northeast. All records were collected on a standard pro-forma sheet which sought precise information on location as well as details of the site type, frog abundance, whether the frogs were seen or heard, and whether they were breeding. Records were plotted on a 10 km square grid across Tasmania. The full results of the survey will be published elsewhere.

The atlas in relation to northeast Tasmania

The boundaries of northeast Tasmania were, for this exercise, the Tamar River to the west and the Fingal Valley road to the south. A total of one hundred and twenty 10 km squares occur within this area, excluding the Furneaux Group of islands. Records from the Furneaux Group have been included in the maps (fig. 1) and are discussed in a separate section. Frogs have been recorded from 87 (72%) of the 120 grid squares, and a total of 927 records in the atlas came from the Northeast. These records included nine of the 11 species of Tasmanian frogs, the other two species being restricted to west Tasmania. Five of the nine species were found to be common and generally widespread through the Northeast. Of the remaining four species, one is very local in Tasmania but does have a small population on the northeast Tasmanian coast. Another species has a generally declining population statewide, but its stronghold is in the Northeast.

Most frogs are spring and summer breeders but there are two autumn-calling and autumn-breeding species in Tasmania. One of these is common and widespread and the other, although common in the Northwest, is very rare in the Northeast. Only one species, *Crinia tasmaniensis,* is endemic to Tasmania and no species is found only in the Northeast.

The frog species found in northeast Tasmania

Brown Froglet, *Crinia signifera* (Girard 1858). The most common and widespread frog in Tasmania. It is well represented in most habitat types throughout the region, especially at lower elevations, being particularly abundant on the coastal plains and the floodplains of the larger rivers. It is common in agricultural land and appears to benefit from human activities especially if these include the creation of water bodies, however small. *C. signifera* is largely replaced by the related *C. tasmaniensis* at higher elevations and in undisturbed bush. Recorded in 67% of all 10 km squares in the Northeast.
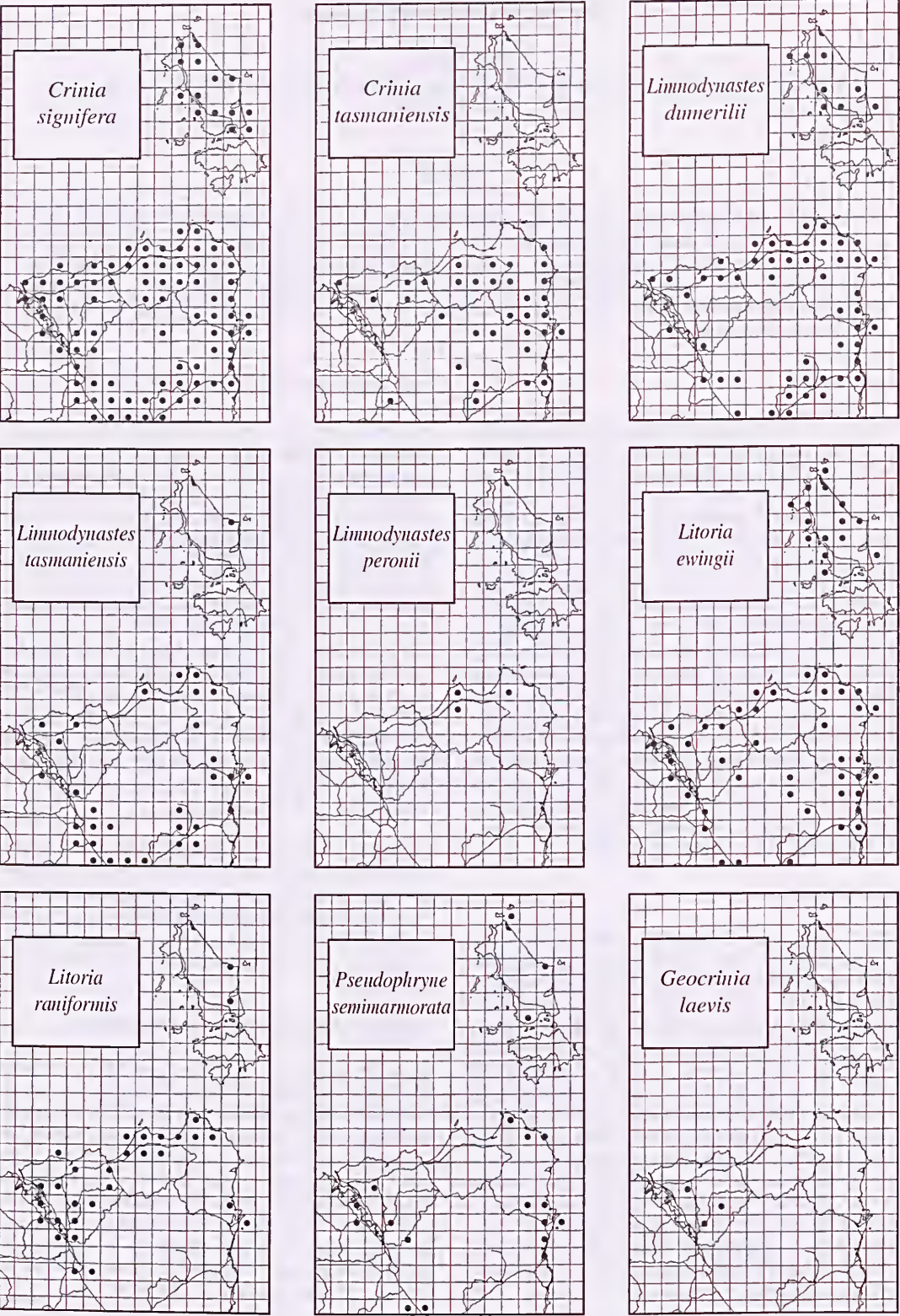
Fig. 1. Frog distribution in northeast Tasmania

Tasmanian Froglet, *Crinia tasmaniensis* (Gunther 1864). Common and widespread in unaltered habitats with temporary creeks and high rainfall. It does occur in some agricultural areas, but here *C. signifera* predominates. Seldom found in coastal dunelands. Most common at higher elevations in grassland, heaths and wet forests, and also in the dry granite forests in the east-facing slopes of the eastern tiers. Very common on the Ben Lomond plateau. Recorded in 28% of squares. Endemic to Tasmania.

Banjo Frog, *Limnodynastes dumerilii* (Parker 1940). Common and widespread throughout the region other than in high-altitude unaltered habitats. It is especially common in flooded swales in coastal dune country and in the floodplains of the Fingal Valley. This species has adapted well to agricultural development and thrives in arable and pasture country where farm dams abound. It is capable of staying underground in torpor for extended periods and responds to heavy rain by appearing in large numbers. Recorded in 42% of squares.

Spotted Marsh Frog, *Limnodynastes tasmaniensis* (Gunther 1858). Has a very similar distribution to *L. dumerilii* in northeast Tasmania although it is not so common along the north coastal plains and down the eastern coast. During late December 1993 it was particularly abundant in the Fingal Valley, breeding in deep pools in receding floodwater. There were no records of *L. tasmaniensis* from forested country or from higher elevations in the central Northeast. Recorded in 26% of squares.

Striped Marsh Frog, *Limnodynastes peronii* (Dumeril & Bibron 1841). This species, not uncommon in Victoria, has a very restricted distribution on King Island and in north Tasmania and may have originally been marooned in north Tasmania by the flooding of the Bassian land bridge. It does not occur in the Furneaux Group. It has a very local distribution in the Northeast, apparently being restricted to coastal lagoons and ponds in the Waterhouse/Cape Portland area. Where *L. peronii* does occur in the Northeast, the population density is considerably lower than in some of the Northwest locations. It is speculated that it was introduced to the Northeast some 30 years ago (R. Green, pers. comm.). This has yet to be confirmed. Recorded in 3 squares only.

Brown Tree-Frog, *Litoria ewingii* (Dumeril & Bibron 1841). The most widely distributed frog species in Tasmania. It is found at all altitudes from sea level to alpine areas and occurs wherever there is permanent or semi-permanent water. *L. ewingii* has benefited from forestry activities and agricultural development. It readily breeds in fire dams, farm dams, water troughs and very temporary water bodies. It is regularly recorded from suburban housing blocks. Due to its habit of calling mainly at night, it was not recorded as frequently as might be expected during the atlas survey, but the distribution of records indicates it is very widespread in the Northeast. *L. ewingii* was not recorded on the Ben Lomond plateau, but coverage there was poor. Small to moderate-sized tadpoles commonly seen swimming in mid-water are more often this species than any other. Recorded in 34% of squares.

Green and Gold Frog, *Litoria raniformis* (Keferstein 1867). This is the largest and most brightly coloured frog in Tasmania. There are nationwide concerns over its fate. This concern includes Tasmania as atlas records reveal a decline in some parts of the State, particularly the Midlands and Northwest. Records in the atlas indicate that the Northeast is a stronghold for this species. There is still a substantial population in the Waterhouse area and the large number of records suggest that the Tamar River valley is another area where several substantial populations occur. *L. raniformis* is also to be found in a few scattered lagoons near St Helens. The causes for its decline are not yet understood but ozone depletion and changing water quality have been promoted as possible reasons. Recorded in 23% of squares.

Southern Toadlet, *Pseudophryne semimarmorata* (Lucas 1892). This species and *G. laevis* are autumn-breeding frogs and are only known to call at that time of the year. Consequently, as frog watchers tend to be less active in the autumn, there are fewer atlas records of these species than for the spring breeders. The Southern Toadlet was recorded on only 37 occasions in the Northeast during the atlas survey. Most of the records came from the St Helens/Binalong Bay area, the Cape Portland/Musselroe River area and along the Tamar. However, there were enough records located over the region to indicate that this frog, primarily found in dry sclerophyll forests, may have been overlooked and may be more widely distributed than the atlas survey indicates. The records suggest it is largely restricted to east Tasmania including Flinders Island. Recorded in 13% of squares.

Smooth Froglet, *Geocrinia laevis* (Gunther 1868). Unlike *P. semimarmorata*, this autumn-breeding frog is an inhabitant of west Tasmania in wet forests, sedgeland plains and coastal dunelands. *G. laevis* was generally thought to be absent from the Northeast; however, there were three confirmed records of the species from the area during the atlas period. It may be a local and uncommon species in the region. Since the completion of the atlas survey the author has found the species in some numbers near Scottsdale. *G. laevis*, like *P. semimarmorata*, lays eggs in capsules in dry or semi-dry locations which fill with water during autumn and winter rains. Tadpoles develop in the capsules and await the rains when they hatch and continue their development in water bodies. These may be as small as a hoof hole.

The significance of the Northeast for Tasmania's frogs

As a region, the Northeast is similar to the Northwest, with nine frog species occurring in each and eight of these common to both. The most significant feature of the region is the large population of *L. raniformis*. This vulnerable species has shown a dramatic population decline in other parts of Tasmania, especially in the Southeast, and the atlas survey suggests it has all but

disappeared from the Northwest. The population of this species centred around Blackmans Lagoon in the Northeast is probably the largest and healthiest in Tasmania.

The northeast Tasmanian population of *L. peronii* is extremely significant, despite some doubts as to its origin (it may have been translocated from the Northwest in a well-intentioned effort to expand the species' range). The Northeast now provides a valuable insurance for the species which has little more than a toehold in Tasmania. There are increasing pressures being placed on the species in the Northwest with rapidly changing agricultural practices in that area due to a dramatic increase in dairying. This has the potential to affect nutrient levels in waterways and dams.

The *C. tasmaniensis* population in the Northeast is isolated from those in west Tasmania and provides an important sub-population of this endemic species. It is not known how different if at all these two populations are, but the geographical separation may be several thousand years old.

Significant frog habitats in northeast Tasmania

Despite the small size of the region (about one-sixth of Tasmania), the Northeast contains several significant frog habitats which are extensive and are occupied by substantial frog populations. The coastal dunelands running the length of the north coast contain outstanding permanent and ephemeral wetlands. Although greatly reduced through draining, they are still important as breeding habitat for *C. signifera*, *L. raniformis*, *L. ewingii*, *L. dumerilii*, *L. peronii* and *L. tasmaniensis*.

The flood plain of the South Esk River from Fingal through to Launceston probably holds the greatest frog biomass in the State, and is comparable only to parts of the East Coast inland from Oyster Bay. At times a deafening chorus of calling frogs may be heard coming from this plain following spring and summer flooding. These calling frogs are predominantly *L. dumerilii*, *L. tasmaniensis* and *C. signifera*.

The northeast Tasmanian highlands, including the Ben Lomond plateau, although still not well investigated for frog populations, are valuable habitat for the endemic *C. tasmaniensis*. In some of the higher areas this was found to be the only frog species present.

Other parts of the Northeast which hold substantial populations of frogs include the heathlands of the Mt William area. There is great frog activity following heavy easterly rains when the area is awash with floodwater. The coastal dunelands in the St Helens area together with their associated wetlands also provide excellent habitats for at least five frog species, including *L. raniformis*.

The Furneaux Group

Whilst not strictly part of the Northeast study area, the Furneaux Group and its atlas records have been included in the accompanying maps (fig. 1). *C. signifera*, *L. dumerilii*, *L. tasmaniensis*, *L. ewingii*, *L. raniformis* and *P. semimarmorata* have been recorded from the islands. *L. tasmaniensis* was not recorded in the atlas but has been recorded since in several locations on Flinders Island and there are also records from there which predate the atlas survey (Martin & Littlejohn 1982). Neither this species nor *L. raniformis* is common, but the remaining four are. There have been very few records from the smaller islands, but *L. dumerilii* was recorded on Vansittart Island.

Threats

There is growing evidence that frogs worldwide are suffering increasing survival problems due to a range of pressures, some well known and others less well understood, and frogs in northeast Tasmania are not immune from these.

Loss of habitat through drainage of wetlands to increase pasture is a long-established agricultural practice. This is perhaps the greatest single threat to frogs and their habitats, especially in coastal wetlands. The spread of the introduced trout is a significant threat, especially in larger water bodies. The extent of damage to frog populations by trout is not well understood, but frogs are known to be a favoured dietary item for trout. Recently publicised concerns over ozone depletion and increased UV radiation (Osborne 1990, Kleiner 1994) may point to a greater threat than is appreciated, particularly to *L. raniformis*, Tasmania's only 'basking' frog. An unidentified virus which is lethal to frogs has been implicated in the disappearance of a number of mainland species in the tropical rainforests of northeast Australia (Trenerry et al. 1994). Whilst there is no evidence of it affecting frogs in Tasmania, there is always a possibility.

The fact that species like *C. signifera* and *L. ewingii* may be extending their ranges with the opening up of the land to agriculture and the increase in number of farm dams is of little comfort. These species are common anyway and are extremely adaptable to change. Other species like *C. tasmaniensis*, *G. laevis* and *L. raniformis* are not so adaptable and are often disadvantaged by these changes. Regular monitoring programs will identify population changes at the species and population levels.

Water is the common requisite for all frogs. Loss of aquatic habitats is the greatest concern for the viability of any frog populations. This includes drainage of important coastal wetlands, a process that has been underway for tens of years in the northeast Tasmanian lowlands, so that now only small areas of wetlands remain of what was formerly prime frog habitat. Blackmans Lagoon and several associated wetlands are within the Waterhouse Protected Area and enjoy long-term protection, but there are many other valuable remnant wetlands on private land in the Northeast. These provide a significant component of the whole area as important frog habitats and are vulnerable to changes. It will substantially help the frog populations of the Northeast if the remaining wetlands are

kept intact. To achieve any security there has to be a will on the part of landowners and this can be best achieved through an increased emphasis on education and community involvement programs.

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Freshwater Fish of Northeast Tasmania with Notes on the Dwarf Galaxias

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Abstract

Northeast Tasmania has 18 species of freshwater fish, of which 15 are native and three are introduced. No species are endemic to the region. Most of the freshwater fishes are diadromous and have a Tasmania-wide distribution, with only three species restricted entirely to freshwater. The most notable feature of the regional fish fauna is the occurrence of the dwarf galaxias, *Galaxiella pusilla*. On mainland Tasmania the Northeast represents the stronghold for this diminutive species, which has a conservation status of 'rare' in Tasmania. There are recreational fisheries for whitebait and salmonids as well as a commercial eel fishery in the Northeast. The biogeographical origins of, threats to and conservation status of the dwarf galaxias in Tasmania are discussed.

Introduction

There are 18 species of freshwater fish recorded from northeast Tasmania, of which 15 are native and three are introduced (table 1). Three of the native species are restricted entirely to freshwater habitats: the dwarf galaxias, *Galaxiella pusilla* (Mack 1936); the river blackfish, *Gadopsis marmoratus* Richardson 1848; and the southern pygmy perch, *Nannoperca australis* Günther 1861. These three species also have the most limited natural distributions of the northeast Tasmanian fish (Fulton 1990). The remaining species have either a marine juvenile phase (e.g. diadromous galaxiids) or a marine adult phase (e.g. eels) as part of their life histories. Diadromous fish undertake regular seasonal migrations between fresh and marine water to complete their life cycle. Whilst some of the diadromous species have landlocked populations far inland which are now completely restricted to fresh water (Humphries 1989, Fulton 1990), it is the coastal regions where the greatest

Table 1. Freshwater fish of northeast Tasmania (Fulton 1990).

Life history: M = migrates to and from sea or estuary, NM = freshwater only.
Habitat: R = rivers, L = lakes, W = wetlands.

Common Name	Scientific Name	Life history	Habitat
Native Fish			
short-headed lamprey	*Mordacia mordax*	M	R
pouched lamprey	*Geotria australis*	M	R
short-finned eel	*Anguilla australis*	M	R/L/W
long-finned eel	*Anguilla reinhardtii*	M	R/L/W
jollytail	*Galaxias maculatus*	M	R/L
spotted galaxias	*G. truttaceus*	M	R/L
climbing galaxias	*G. brevipinnis*	M	R
Tasmanian mudfish	*G. cleaveri*	M	R/W
dwarf galaxias	*Galaxiella pusilla*	NM	R/W
Tasmanian whitebait	*Lovettia sealii*	M	R
Australian grayling	*Prototroctes maraena*	M	R
Tasmanian smelt	*Retropinna tasmanica*	M	R
river blackfish	*Gadopsis marmoratus*	NM	R/L
southern pygmy perch	*Nannoperca australis*	NM	R/W
sandy	*Pseudaphritis urvillii*	M	R
Introduced Fish			
brown trout	*Salmo trutta*	M	R/L
Atlantic salmon	*S. salar*	M	R/L
rainbow trout	*Oncorhynchus mykiss*	M	R/L

number of populations occur. Diadromous fishes occur throughout Tasmania, presumably because of their ability to colonise rivers from the sea, whereas the restricted distribution of the three totally freshwater species probably relates to their inability to survive in the marine environment. The dwarf galaxias, river blackfish and pygmy perch probably only occur in catchments successfully colonised several thousands of years ago, although floods may have occasionally linked rivers in adjacent catchments and there may have been translocations by humans and animals, allowing cross-catchment dispersal. All three totally freshwater species have a trans-Bass Strait distribution and the land bridge which existed between mainland Australia and Tasmania until approximately 6 000 years ago (Galloway & Kemp 1981), would have been the most likely route for dispersal between the two areas.

Recreational fisheries

There are two recreational fisheries (excluding the giant freshwater lobster fishery) in northeast Tasmania, of which the most patronised is based on introduced salmonids. There are self-sustaining brown trout populations in most rivers but populations of trout in Blackmans Lagoon and Little Waterhouse Lake, and of Atlantic salmon in Big Waterhouse Lake, are maintained by a stocking program. A brook trout fishery was trialed at a storage near Derby in 1966 (Lynch 1967) but failed when stocking was discontinued.

Whitebait species are the basis for a second recreational fishery. A commercial whitebait fishery in Tasmania commenced in 1941, although small-scale commercial fishing had occurred since the early 1930s (Fulton & Pavuk 1988). Between 1945 and 1974 a licensed commercial whitebait fishery existed in the Great Forester River, based primarily on migrations of the Tasmanian whitebait, *Lovettia sealii* (Johnston 1883). The Northeast regional whitebait harvest averaged nearly 29 500 kg per year during the period 1945-48 although there was significant inter-annual variation in harvests (figures derived from Blackburn 1950). These harvests contributed between 0.2 and 13% of the total statewide harvest for that period (figures derived from Blackburn 1950). Poor statewide catches in the late 1940s and failures to attain quotas in the 1950s resulted in the closure of the fishery in 1974. Since a limited recreational whitebait fishery was re-established in 1990, harvests in the Great Forester River have regularly exceeded harvests in other open rivers (Inland Fisheries Commission 1991, 1992, 1993). Excellent catches have made the Great Forester River the most popular river for whitebait fishing in Tasmania (table 2). In contrast to the *Lovettia*-based commercial fishery of 20-50 years ago, the recreational fishery is based primarily on migrating *Galaxias* spp.

Commercial eel fishery

Two species of eels; short-finned eel, *Anguilla australis* (Richardson 1848) and long-finned eel, *Anguilla reinhardtii* (Steindachner 1867), are harvested from the wild in the Northeast. During the period 1983-94 over 161 000 kg of short-finned eels and over 7 500 kg of long-finned eels were landed by licensed eel fishermen. Short-finned eel harvests in this region can be significant, with an annual harvest of up to 63% of the statewide total. Fishing of long-finned eels is largely restricted to the major coastal lagoons between Waterhouse and Cape Portland in the Northeast.

Conservation of native freshwater fish of northeast Tasmania

Most of the freshwater fish species occurring in northeast Tasmania are widely distributed with no species endemic to this region. There appears to be no immediate threat to
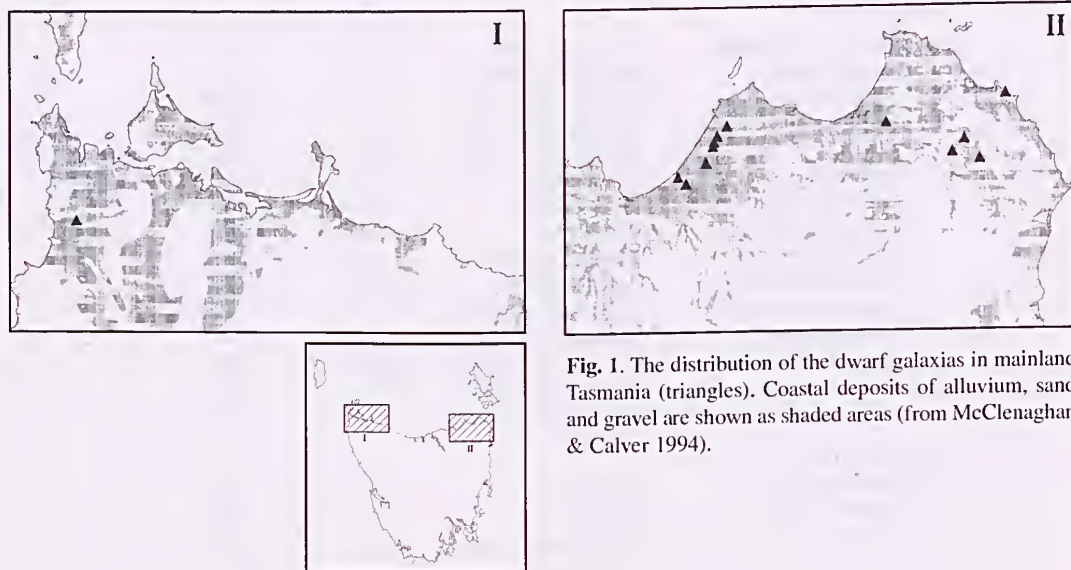

Fig. 1. The distribution of the dwarf galaxias in mainland Tasmania (triangles). Coastal deposits of alluvium, sand and gravel are shown as shaded areas (from McClenaghan & Calver 1994).

Table 2. Recreational whitebait fishery statistics for northeast Tasmania, 1990-92. Data from Inland Fisheries Commission volunteer survey forms.

Year	Number of fishers	Estimate of total harvest (kg)
1990	110	740
1991	190	1 300
1992	140	1 100

the majority of these species and consequently their conservation is not a priority. One exception is the Australian grayling, *Prototroctes maraena* Günther 1864, which despite being distributed throughout coastal southeast Australia is considered 'vulnerable' (Wager & Jackson 1993, Vertebrate Advisory Committee 1994). Grayling have been recorded in the Northeast from the Scamander, Ansons, Tamar and North Esk Rivers (Bell et al. 1980). Although this species has been in decline throughout Australia since early this century, records from electrofishing surveys and anecdotal information from anglers in recent years have indicated an increase in numbers of grayling in rivers across the north coast of Tasmania (J. Diggle, pers. comm.). Despite this apparent resurgence, barriers to migration, river flow regulation, loss of riparian vegetation, siltation and habitat alteration, which are the primary factors threatening grayling (Wager & Jackson 1993), still occur in northeast Tasmania.

A second species requiring conservation is the dwarf galaxias, which is considered 'rare' in Tasmania (Vertebrate Advisory Committee 1994) and 'vulnerable' in mainland Australia (Wager & Jackson 1993). Fulton (1990) recorded the dwarf galaxias from only six locations in mainland Tasmania, all in the far Northeast. Recent surveys by the authors have increased the number of locations to 11 in this region and another population has been located east of Mt Cameron in northwest Tasmania (P. Brown and H. Wapstra, pers. comm.) (fig. 1). (This last record derives from field observations - specimens were neither lodged at any institution nor examined by the authors.) The 'rare' status of the dwarf galaxias in Tasmania is based on a low number of known populations rather than a precise assessment of threatening processes, and there is a paucity of information on population sizes and habitat determinants of this species. Several threats have been identified which have been implicated in the decline of dwarf galaxias on the Australian mainland (Wager & Jackson 1993). These are the drainage of wetland habitats (Koehn & Morrison 1990), channelisation, removal of aquatic riparian vegetation and interactions with mosquito fish, *Gambusia affinis* Baird and Girard 1853, and redfin perch, *Perca fluviatilis* Linnaeus 1758 (Koehn 1990). Destruction and eutrophication of wetlands, anthropogenic alterations to hydrology and introductions of exotic fishes are the most likely threats to dwarf galaxias in Tasmania.

Distribution, life history and habitat of dwarf galaxias

The dwarf galaxias has the most limited distribution of all the non-endemic fish in Tasmania, with the majority of records from east of Bridport to Ansons Bay (fig. 1). Dwarf galaxias are also found on Flinders Island and in southeast mainland Australia from southeast South Australia through to Gippsland in Victoria, but the species does not occur north of the Great Dividing Range (McDowall & Frankenberg 1981).

The dwarf galaxias is one of the smallest members of the Galaxiidae, a Southern Hemisphere equivalent of the Salmonidae (McDowall & Frankenberg 1981). Galaxiids show two broad types of life cycle strategy. One group, typified by dwarf galaxias and two congeneric species in southwest Australia, spends its entire life in fresh water whereas the other has a marine juvenile phase. This latter group generally spawns in the lower reaches of streams; the newly hatched larvae are washed to sea and grow for several months in the comparatively rich marine environment until they return to freshwater as juvenile whitebait (McDowall & Frankenberg 1981). The dwarf galaxias is unusual in the Galaxiidae in that it exhibits sexual dimorphism (McDowall 1978). Mature males develop a bright red stripe down their flanks and are smaller than the comparatively drab females. The species spawns in late winter and early spring, lays comparatively few eggs and apparently dies soon after spawning (Humphries 1986). Fish may possibly aestivate if their habitat dries over summer and may have the ability to survive protracted periods in habitats without free water. For this purpose they apparently utilise burrows dug by yabbies (e.g. *Geocharax* in South Australia) or even make small depressions in mud or under rocks (Humphries 1983, Beck 1985).

In surveys conducted in northeast Tasmania, on Flinders Island and in mainland Australia, the habitats found to be occupied by dwarf galaxias shared certain characteristics (Backhouse & Vanner 1978; Jackson & Davies 1983; Humphries 1986; Chilcott and Humphries, unpublished data). Populations are associated with permanent or semi-permanent flowing water, often with a swamp, soak or marsh located nearby. Although association with a permanent creek seems to be most common, dwarf galaxias also occur in areas which apparently dry completely on a regular basis. Whether this is because the species can survive through aestivation, or by rapid colonisation from more permanent water bodies when

connections re-establish, or both, is uncertain (Beck 1985). Dwarf galaxias are virtually always found associated with dense aquatic vegetation, as are pygmy perch, with which they often co-occur. Dwarf galaxias presumably use aquatic macrophytes as cover and also as a substratum upon which to deposit eggs (Backhouse & Vanner 1978).

Biogeography of *Galaxiella* species

The two Western Australian *Galaxiella* species, *G. munda* (McDowell 1978) and *G. nigrostriata* (Shipway 1953), occur only in the southwest of that state, whereas *G. pusilla* only occurs in southeast Australia (McDowall & Frankenberg 1981). The explanation for this pattern of distribution is uncertain and the lack of fossils of ancestral groups (Harris 1984) means that a theory to account for their current distributions is largely based on circumstantial evidence. Each *Galaxiella* species is confined to coastal drainages, apart from a population of dwarf galaxias occurring in Bool Lagoon in southeast South Australia. It has been hypothesised, however, that this latter population is a result of translocation by man (Beck 1985). Although several other galaxiid species have distributions similar to that of the *Galaxiella* species, each of these is diadromous and thus it is possible that colonisation of freshwater habitats could have occurred via the sea. Since the three *Galaxiella* species are restricted to fresh water, it would be logical to presume that their current distribution is a result of dispersal via fresh waters. Many other freshwater taxa share the disjunct southeast and southwest Australian distribution of the genus *Galaxiella*, including nannopercid fish of the genus *Edelia* (Allen 1989), ancylid limpets (Williams & Campbell 1987), gripopterygid stoneflies (Hynes & Bunn 1984), hyriid mussels (Walker 1981) and several genera of frogs (Cogger 1979). One hypothesis relating to the distribution of *Galaxiella* species relies on *G. pusilla* and *G. nigrostriata* being more closely related to each other than either is to *G. munda,* and their being more derived; in other words, *G. munda* is the primitive sister taxon of the other two species (R. M. McDowall, pers. comm.). If this is true, it may be that the origin for the *Galaxiella* group was in Western Australia, which means that the ancestor of *G. pusilla* must have dispersed eastwards.

An alternative hypothesis is that all three species evolved from one ancestral species in the relatively recent past. About 18 000 years ago, sea levels were considerably lower than they are now, with a large expanse of the relatively shallow continental shelf exposed (Galloway & Kemp 1981). De Deckker (1986) has suggested that there was a series of freshwater lagoons along the south coast of Australia and that these water bodies may have acted as refuges for aquatic fauna. Furthermore, Frakes et al. (1987) have postulated that in this region rivers also may have existed, which we suggest may have permitted movement of fish along the southern coast of Australia. When sea levels rose at the end of the glacial period, populations of the ancestral *Galaxiella*, which were

distributed along the south coast in the lagoons, became isolated and fragmented and were finally restricted to suitable environments in the vicinity of current distributions. Subsequent evolution could then have resulted in the three extant species.

A third hypothesis to explain the current distributions of *Galaxiella* is based on the presumption that the centre of galaxiid evolution was in southeast Australia. This assumes that the location of the greatest number of species of a taxonomic group tends to be the centre of speciation and dispersal (see Heatwole 1987). Seventeen of a total of twenty Australian galaxiid species occur only in southeast Australia, with fifteen species found in Tasmania alone (McDowall & Frankenberg 1981). Only five species of galaxiid are found in southwest Australia and only three of these are endemic (Allen 1989).

The diversity of galaxiids in Tasmania indicates that this region has been important in the evolution of new species. However, the past existence of a Bass Strait land bridge has meant that there has been the potential for both southward and northward dispersal of galaxiids and other freshwater species. That *G. marmoratus, N. australis* and *G. pusilla* did not disperse farther inland suggests that the route for dispersal of these species was southward (Frankenberg 1974). If it is assumed that the ancestral *Galaxiella* evolved in southeast Australia before or during the Pleistocene, then a mechanism postulated for the Australian biota as a whole by Horton (1984) could explain current distributions. The Pleistocene was a period of great climatic, sea level and geomorphological change (Galloway & Kemp 1981, Keast 1981) and '...*shifting barriers, boundaries and corridors and ... repeated cycles of isolation and renewed contact of populations*' (Heatwole 1987) made the period ripe for rapid speciation. According to the model of Horton (1984), initially extensive arid zones during the Pleistocene blocked the dispersal of freshwater species westwards, but then a wet phase allowed south coastal species to move along a southern corridor into southwest Australia and, at times of low sea levels, into Tasmania. A later arid period then isolated populations in the southeast and southwest of the continent. Some degree of adaptation to semi-arid environments may have occurred prior to the evolution of the three *Galaxiella* species, since there is circumstantial evidence that each has the ability to aestivate when its habitat dries (Humphries 1983; Beck 1985; Pen et al. 1993; H.S. Gill and D. Morgan, pers. comm.).

Fossil evidence and the determination of phylogenetic relationships of the *Galaxiella* species would help decide which of the three biogeographical hypotheses is the most plausible. Regardless of which hypothesis is correct, the northeast Tasmanian and Flinders Island populations of *G. pusilla* occur mainly in recently formed environments (McClenaghan & Calver 1994). When the sea attained its present level in the Holocene and the Bass Strait land link no longer existed, coastal features such as swamps,

mudflats and lagoons developed rapidly and extensively (Galloway & Kemp 1981). The Tasmanian and mainland Australian populations of *G. pusilla* became separated and subsequent dispersal would have been limited largely to the catchments within which populations found themselves at the beginning of the Holocene.

Conclusion

The freshwater fish fauna of northeast Tasmania is notable for its lack of regional endemics, the dominance of diadromous species and the occurrence of the vulnerable Australian grayling and the rare dwarf galaxias. The region is undoubtedly the stronghold of Tasmanian mainland populations of the dwarf galaxias although a recent discovery of a population near Mt Cameron in the Northwest of the State indicates that the species is more widespread than previously thought. There is some evidence to suggest that the distribution of the dwarf galaxias may be strongly associated with wetland habitats situated on sand, gravel and alluvium coastal landforms formed during the Holocene, but more intensive study is required to confirm this relationship. There is also a need to identify and assess threatening processes which may be placing populations of the dwarf galaxias at risk in the Northeast.

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Coastal Heathland Spiders: Spatial Distribution and Biogeographic Significance

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Abstract

The spider fauna of Tasmania has attracted international interest due to the presence of many endemic taxa of high biogeographic significance. A survey of the coastal heathland at Waterhouse Point and Eddystone Point in the Northeast has revealed the presence of such taxa, with Gondwanan distribution patterns, which have been traditionally collected from rainforests and wet sclerophyll forests. After a 16 month survey on four coastal heathland sites, a total of 8 625 spiders was collected that comprised an unexpectedly high level of taxonomic richness: 33 families, 97 genera, and 130 species. Of these, 26% of genera and 88% of species were undescribed, with many species predicted to be endemic to the heathlands. Waterhouse Point had more families, genera and species than Eddystone Point, with 21 species (16%) and 18 species (14%) unique to these locations, respectively. All species unique to sites comprised less than 0.5% of total spider abundance. To assess biogeographic significance, species and their higher-level taxa were allocated to four biogeographic categories: cosmopolitan, Gondwanan, Australian and Tasmanian. Eight families and 14 genera had elements of a Gondwanan distribution which accommodated 17% of species. Further refinement to place the Northeast fauna in a Tasmanian context was limited by current constraints in reconciling undescribed taxa from other collections. Nevertheless, these results support the recognition of the coastal heathland as being of high conservation significance, with the maintenance of a heterogeneous plant community important for retaining the observed patterns of spider biodiversity.

Introduction

The coastal heathlands of northeast Tasmania contain a diversity of plant communities threatened by processes of fragmentation and degradation (Kirkpatrick 1977). Effective conservation and management of this habitat requires an understanding of the composition of the flora and fauna, as well as the factors that influence patterns of biodiversity. In terms of fauna, invertebrates comprise the most diverse and abundant component of natural systems, with many taxa linked to critical ecological processes (New 1995). Invertebrates of the northeast Tasmanian heathlands, however, have been poorly studied, despite the opportunity they present to cost-effectively derive quantitative, and ecologically meaningful, data. In 1986, the Plomley Foundation, through the Queen Victoria Museum and Art Gallery, provided a valuable opportunity to fund a survey of the Araneae (spiders), which are dominant invertebrate predators and among the six or seven most speciose orders worldwide (Coddington et al. 1991).

Australian spiders attract international interest due to the richness of taxa and their significance to historical biogeography through Gondwanan origins (Raven 1980; Forster & Platnick 1984, 1985; Platnick 1988; Platnick & Forster, 1989; Forster et al. 1990; Jocque 1991, 1993). Within Australia, the Tasmania fauna is likely to be the most biogeographically important, with high levels of endemism and relict taxa (Raven & Gallon 1987). At present, Australia can claim 81 of the 105 spider families known worldwide, with one endemic family and another

nine families endemic to both Australia and New Zealand (Raven 1988; Platnick 1989, 1993). Tasmania has special significance as it harbours most of the tiny litter-dwelling families (many of high phylogenetic value) and the endemic genus Hickmania, named in honour of V.V. Hickman (1926-84), who described many Tasmanian taxa including four new families. Hickman, however, focused on south Tasmania; subsequent surveys focussed on rainforest or wet sclerophyll forests, leaving the drier parts of the Northeast unexplored.

Determining the biogeographic significance of spider taxa is currently limited by the fact that only an estimated 30% (Davies 1985) or 20% (Raven 1988) of Australia's fauna has been formally described. Even with an increasing effort to survey invertebrates (e.g. Coy et al. 1993), reconciliation of undescribed taxa from separate collections is, unfortunately, a project in itself. Data are therefore currently unavailable to place the distribution patterns of the majority of species collected in a statewide or regional context. Accordingly, an attempt was made to consider the distributions of heathland taxa at the scales possible based on published data and the trends in endemicity of described taxa.

Methods and study areas

Spider sampling

Spiders were collected over 16 months from October 1986 to January 1988 at regular four week intervals. Three complementary sampling methods (pitfall trapping,

sweep netting and visual search) were adopted and details of the methodology are given in Churchill (1993). The results from all three sampling methods are combined and presented here. A spatially stratified, random sampling design was used which accommodated four spatial scales, with species distributions documented here at two scales: location and site.

Locations

Two widely separated locations were selected: Waterhouse Point, east of Bridport, and Eddystone Point at the southern end of Mt William National Park. These locations provided relatively large heathland areas protected from inappropriate land use, and a conspicuous lack of introduced plants was evidence for a history of minimal disturbance. Moreover, Waterhouse Point had been listed as an urgent priority for research efforts (Kirkpatrick 1977).

Sites

At each location, two 90 x 90 m sites were selected that clearly differed from each other structurally and floristically but which were relatively homogenous: Site 1 and Site 2 at Waterhouse Point; Site 3 and Site 4 at Eddystone Point.

At Waterhouse Point, Site 1 (latitude 40°50'51", longitude 147°38'07") was a relatively open heath of medium height dominated by *Xanthorrhea* spp., *Bauksia marginata*, *Allocasuarina monolifera* and *Epacris impressa*. Situated on coastal hind dunes, this site had an easterly aspect that provided almost direct exposure to the sea. By contrast, Site 2 (latitude 40°50'20", longitude 147°40'45") was a low, closed heath which lay behind the dunes on the coastal plain and consequently was less exposed to the sea than Site 1. Relatively flat, Site 2 was dominated by *Banksia marginata*, *Allocasuarina monolifera*, *Epacris impressa* and *Lomandra longifolia*. A range of species in the family Fabaceae and some sedge species also characterised this site.

At Eddystone Point, Site 3 (latitude 40°59'44", longitude 148°19'27") was a more heterogenous heath in terms of height and species composition than sites at Waterhouse Point. Dominated largely by *Xanthorrhea* spp., *Leptospermum scoparium* and *Bauksia marginata*, Site 3 had a notable sedge and *Selaginella uliginosa* component due to poor drainage, with an occasional small tree of *Eucalyptus amygdalina* on the relatively elevated areas. Site 4 (latitude 41°00'02", longitude 148°19'15") was a low heath of even height conspicuously dominated by *Ricinocarpus pinifolius*, *Hypolaena fastigiata*, *Aotus* spp. and *Leptospermum scoparium*. On this site, an abundance of *Selaginella uliginosa* and the proximity of a swamp behind the primary beach dune indicated poor drainage qualities of the soil.

Biogeographic analysis

Spider taxa were allocated to four broad biogeographic categories: cosmopolitan - with a wide or disjunct distribution pattern; Gondwanan - in the broadest sense, including 'late Gondwanan' distributions in Australia, the Western Pacific islands, New Zealand and South America; Australian - including eastern, southern or widespread mainland patterns; and Tasmanian - known only from Tasmania. Allocation of described spider taxa to these categories was based on the published distribution records of Forster (1970), Forster and Blest (1979), Forster et al. (1988), Gray (1983a, 1983b), Hickman (1930, 1948, 1951, 1967, 1969), Jocque (1991), Platnick (1989, 1990, 1993), Rainbow (1911) and Roewer (1942, 1954). The classification of unnamed genera and species was based on expected levels of endemicity in the group, and the current taxonomic affinities of its relatives. These latter decisions were supported by two Australian taxonomists: Dr Robert Raven (Queensland Museum) and Dr Mark Harvey (Western Australian Museum).

Results

Spider diversity

Over the survey period, a total of 8 625 spiders was collected that were assigned to 33 families, 97 genera and 130 species. Of these, 26% genera and 87% of species could not be named. A diversity of foraging types was represented: active ground and foliage hunters (amaurobiids, clubionids, corinnids, gnaphosids, heteropodids, lycosids, salticids, zodariids and zorids), foliage ambushers (thomisids), sheet web builders above the ground (linyphiids, nicodamids, oecobiids), web builders in foliage (araneids, desids), web builders in litter (hahniids, cyatholipids, micropholcommatids) and litter foragers (hadrotarsids, pararcheids).

Spatial distribution of taxa

Across the four study sites, 69% of taxa occurred at both Waterhouse Point and Eddystone Point, 35% on all four sites, 25% on three sites, and 9% on two sites (Table 1). Waterhouse Point had more families, genera and species than Eddystone Point (Table 2). Waterhouse Point had 21 species (16%) and Eddystone Point 18 species (14%) that were restricted to these locations (Table 2). At the site scale, Site 3 consistently had the lowest number of taxa, Site 4 had the most genera and Site 2 had the most families and unique species (Table 2).

Biogeographic classification of taxa

Only two biogeographic categories were relevant at the family level: cosmopolitan and Gondwanan (table 1). Eight families had a Gondwanan distribution, and had 58% and 42% of Gondwanan and Australian genera, respectively. For the 25 cosmopolitan families, genera were 30% cosmopolitan, 10% Gondwanan, 60%

Australian and 1% Tasmanian (table 1). Species which belonged to cosmopolitan families dominated all sites (>85%) with the Gondwanan proportion being slightly greater on Site 1 (14%) than sites 2-4 (9-11%).

Genera could be allocated to all four biogeographic categories: 25 % cosmopolitan, 16% Gondwanan, 58% Australian and 1% Tasmanian. Species in Australian genera dominated all sites (51-58%). The cosmopolitan component varied between 25-29% and the percentage of species in Gondwanan genera was highest on Site 3 (19%) and ranged from 15-16% on other sites.

For species, all biogeographic categories were relevant, although there was only one cosmopolitan species that occurred on Site 2: the introduced *Oecobius annulipes* Lucas, 1846. One species, *Stiphidion facetum* Simon 1902, with a broad Gondwanan distribution, was recorded across all sites. Species with an Australian distribution comprised from 26% (site 2) to 33% (site 1) and species limited to Tasmania dominated all sites with 66-72%. However, these Australian and Tasmanian species frequently belonged to genera or families with Gondwanan distributions (table 1).

Discussion

The northeast Tasmanian coastal heathlands contain a diverse and abundant spider fauna including a high proportion of new taxa, emphasising the need for taxonomic revision of many Australian groups (Davies 1985, Raven 1988). With respect to surveys conducted to date in Australia, this heathland spider community displayed unexpectedly high levels of richness (R. Raven, pers. comm.). Moreover, the fauna included families and genera of notable biogeographic interest that had been previously recorded from moss and leaf litter in rainforests of southwest Tasmania (Hickman 1948, 1969; Forster & Platnick 1984; Coy et al. 1993). Spider taxa related to drier habitats with Gondwana-related distributions were also identified from this survey (Jocque 1991, Platnick 1988). Due to the high levels of endemism characteristic of many of these taxa, and the fact that most species are undescribed, it is predicted that the coastal heathland of the Northeast harbours spider species restricted to this habitat.

Within the biogeographic categories to which species and their higher-level taxa were allocated, certain patterns emerged. Sites were dominated by cosmopolitan families, Australian genera and species in the Tasmanian category. Beyond the broad category of Tasmanian, the biogeographic relevance of taxa occurring in the Northeast or at each location cannot be determined without further research. Collections of spider material from a range of other Tasmanian localities do exist but comparisons require a standardised approach to identification of, and reference to, undescribed taxa. The lack of such a reference system is currently limiting the evaluation of the significance of invertebrate communities

Australia-wide (Cranston 1990, Kitching 1993). The proportion of biogeographic categories at each taxonomic level did not reveal any notable differences between sites. Nevertheless, the composition of the spider community varied spatially, mostly at the site scale, and this has been associated with patterns of variation in the heathland vegetation (Churchill 1995). The implications for management at this stage therefore, are that the heterogenous nature of the plant community needs to be maintained to sustain the observed levels of spider biodiversity.

In terms of richness of taxa, Waterhouse Point had more spider taxa, and more unique taxa, than Eddystone Point. However, many of these species were rare, often as a result of the capture of one individual after 16 months of sampling. It is possible that the most appropriate technique may not have been used to target such species, since the three sampling methods used were biassed differentially towards particular taxa (Churchill 1993). Future invertebrate surveys should adopt a consistent methodology which standardises sampling effort across space and time, to facilitate a valid comparison of data sets (Yen & Butcher 1992) and a more accurate perception of the composition of the fauna (Churchill 1995). For taxa perceived as rare, a broad range of sampling methods should be used over all seasons to confirm that this status is not merely a function of inadequate sampling effort.

Invertebrates from rainforest and wet sclerophyll forests have been considered most worthy of conservation efforts, particularly in Tasmania (Yen & Lillywhite 1990, Coy et al. 1993). In contrast, invertebrates in habitats such as coastal heath have received a lower research priority, despite the rapid rate at which this habitat, at least, is being cleared and fragmented (Kirkpatrick 1977). The issue has been compounded by a lack of data from which habitat significance can be evaluated. To identify areas of high biodiversity and conservation priority, criteria currently emphasise the presence of fauna with high levels of endemism and/or importance to evolutionary processes (Platnick 1991, Greenslade 1994, New 1994). Since the spider taxa recorded here display these attributes, the coastal heathlands of the Northeast include areas of high conservation significance for invertebrates. The future value of conserving these heathlands also relates to the opportunity to research processes of evolution and adaptation of Tasmania's ancient fauna to increasingly drier habitats. The direct relevance of this to the effective conservation and management of relict faunas and our natural resources is highlighted by the fact that the impact of global climate change on biodiversity is now a research priority (Steffan & Walker 1992).

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Table 1. List of heathland spider taxa, their presence (x) at Site 1 and Site 2 (Waterhouse Point), and at Site 3 and Site 4 (Eddystone Point), and their allocated biogeographic category: cosmopolitan (C), Gondwanan (G), Australian (A) or Tasmanian (T).

| TAXA | WATERHOUSE POINT | | EDDYSTONE POINT | | CATEGORY | |
	Site 1	Site 2	Site 3	Site 4	Genus	Species
Amaurobiidae	X	X	X	X	(C)	
Rubrius milvinus	-	X	-	-	G	T
Genus A sp.1	X	X	X	X	A	T
Genus A sp.2	X	X	X	X	A	T
Genus B sp.	X	X	X	-	A	T
Genus C sp.	-	X	X	X	A	T
Genus D sp.	-	-	X	X	A	T
Amphinectidae	-	-	X	X	(G)	
Mamoea sp.	-	-	X	X	G	T
Araneidae	X	X	X	X	(C)	
Cyclosa sp.	X	X	X	X	C	A
Eriophora biapicata	X	-	X	X	C	A
Gasteracantha minax	X	-	-	X	C	A
Genus E sp.	-	X	-	X	A	T
Genus F sp.	X	-	-	-	A	T
Genus G sp.	-	X	X	X	A	T
Genus H sp.	-	-	X	-	A	T
Genus I sp.	-	X	X	-	A	T
Clubionidae	X	X	X	X	(C)	
Cheiracanthium sp.	X	X	X	X	C	A
Clubiona sp.1	X	X	X	X	C	T
Clubiona sp.2	X	X	X	X	C	T
Clubiona sp.3	X	-	-	X	C	T
Genus J sp.	-	-	-	X	A	T
Corinnidae	X	X	X	X	(C)	
Asadipus sp.	X	X	X	X	G	T
Castianeira sp.	X	X	X	X	C	T
Supunna sp.	X	X	-	-	A	T
Cyatholipidae	X	X	-	X	(G)	
Hanea sp.	-	-	-	X	G	T
Matilda sp.	X	X	-	-	A	T
Desidae	X	X	X	X	(C)	
Austmusia sp.	-	-	X	X	A	T
Baduuma vandiemani	X	X	X	X	G	T
Forsteria sp.	X	-	-	X	A	T
Tuakana sp.	X	X	-	-	G	T
Dictynidae	X	X	X	X	(C)	
Callevophthalmus sp.1	X	X	X	X	A	T
Callevophthalmus sp.2	-	-	X	X	A	T
Gnaphosidae	X	X	X	X	(C)	
Anzacia sp.1	X	X	X	-	G	T
Anzacia sp.2	X	X	X	X	G	T
Eilica sp.	X	X	X	X	G	T
Megamyrmaekion sp.	X	X	-	X	C	T
Micaria sp.	X	X	X	X	C	T
Trachycosmus sp.	X	X	X	X	T	T

TAXA	WATERHOUSE POINT		EDDYSTONE POINT		CATEGORY	
	Site 1	Site 2	Site 3	Site 4	Genus	Species
Zelotes sp.1	X	-	X	X	C	T
Zelotes sp.2	-	X	X	X	C	T
Zelotes sp.3	-	X	-	X	C	T
Genus K sp.	-	X	-	-	A	T
Genus L sp.	-	X	-	-	A	T
Hahniidae	X	X	-	X	(C)	
Neoaviola sp.	X	X	-	X	A	T
Heteropodidae	X	X	X	X	(C)	
Neosparassus sp.	X	X	X	X	A	A
Linyphiidae	X	X	X	X	(C)	
Laetesia sp.1	X	X	X	X	A	T
Laetesia sp.2	X	X	X	X	A	T
Laetesia sp.3	X	X	X	X	A	T
Laetesia sp.4	-	-	X	-	A	T
Genus N sp.	X	-	X	X	A	T
Genus O sp.	-	X	X	X	A	T
Lycosidae	X	X	X	X	(C)	
Artoria neboissi	X	X	X	X	C	A
Artoria sp. 1	-	X	X	X	C	T
Artoria sp. 2	X	X	X	X	C	T
Artoria sp. 3	X	X	X	X	C	T
Lycosa funesta	X	X	X	X	C	A
Lycosa speciosa	-	X	X	X	C	A
Lycosa sp.	X	X	-	X	C	A
Micropholcommatidae	X	X	X	X	(G)	
Micropholcomma sp.1	X	-	X	-	A	T
Micropholcomma sp.2	X	X	-	X	A	T
Textricella sp.1	X	X	X	-	G	T
Textricella sp.2	X	X	X	X	G	T
Textricella sp.3	X	-	X	X	G	T
Mimetidae	-	X	-	-	(C)	
Australomimetus sp.	-	X	-	-	A	T
Miturgidae	X	X	X	X	(C)	
Miturga sp.1	X	X	X	X	A	T
Miturga sp.2	-	X	-	-	A	T
Uliodon velox	X	X	-	X	A	T
Mysmenidae	X	X	-	-	(C)	
Genus P sp.	X	X	-	-	A	T
Nicodamidae	X	X	X	X	(G)	
Genus Y sp.	X	X	X	X	A	A
Oecobiidae	-	X	-	-	(C)	
Oecobius annulipes	-	X	-	-	C	C
Oonopidae	X	X	-	-	(C)	
Orchestina sp.	-	X	-	-	C	T
Genus Q sp.	X	-		-	A	T

TAXA	WATERHOUSE POINT Site 1	Site 2	EDDYSTONE POINT Site 3	Site 4	CATEGORY Genus	Species
Oxyopidae	-	-	-	X	(C)	
Genus R sp.	-	-	-	X	A	T
Pararcheidae	X	X	X	-	(G)	
Pararchaea sp.	X	X	X	-	G	T
Pisauridae	-	-	X	-	(C)	
Dolomedes sp.	-	-	X	-	C	A
Prodidomidae	X	X	X	X	(C)	
Molycria sp.	X	X	X	X	A	T
Salticidae	X	X	X	X	(C)	
Lycidas sp.	X	X	X	X	A	A
Maratus sp.	X	X	X	X	A	A
Opisthoucus sp.	-	X	X	X	A	A
Pseudosynagelides sp.	-	X	-	-	A	A
Servaea sp.	X	X	-	-	A	A
Genus S sp.1	X	-	X	-	A	A
Genus S sp.2	X	X	-	-	A	A
Genus S sp.3	-	-	X	X	A	A
Genus S sp.4	X	-	-	-	A	A
Genus T sp.	X	-	X	-	A	A
Genus U sp.	-	-	-	X	A	A
Genus V sp.	X	X	-	X	A	A
Genus W sp.	-	-	-	X	A	A
Genus X sp.	X	-	-	-	A	A
Stiphidiidae	X	X	X	X	(G)	
Baiami sp.	X	X	X	X	G	T
Corasoides australis	X	-	-	X	A	A
Stiphidion facetum	X	X	X	X	G	G
Tetragnathidae	X	X	X	X	(C)	
Delioclus sp.	X	X	X	X	A	A
Phonognatha sp.	-	X	X	X	A	A
Tetragnatha sp.	-	X	X	X	C	A
Theridiidae	X	X	X	X	(C)	
Achaearauea sp.	X	-	-	-	C	A
Dipoeua sp.	-	-	X	-	C	A
Episiuus sp.	X	-	X	X	C	A
Euryopis sp.	X	-	X	X	C	A
Hadrotarsus sp.1	-	-	X	X	A	T
Hadrotarsus sp.2	-	-	X	-	A	T
Phoroucidia trituberculata	-	-	X	-	C	A
Steatoda sp.1	X	-	-	X	C	A
Steatoda sp.2	X	X	-	-	C	A
Steatoda livens	X	X	-	X	C	T
Theridiou sp.	X	X	X	X	C	A
Genus M sp.	X	X	-	-	A	T
Thomisidae	X	X	X	X	(C)	
Cymbacha sp.	X	X	X	X	G	A
Diaea sp.	X	X	X	X	C	A
Sidymella sp.1	X	X	-	X	G	T

TAXA	WATERHOUSE POINT		EDDYSTONE POINT		CATEGORY	
	Site 1	Site 2	Site 3	Site 4	Genus	Species
Sidymella sp.2	-	X	X	-	G	T
Sidymella sp.3	X	X	X	X	G	T
Sidymella sp.4	X	X	X	X	G	T
Sidymella longipes	X	X	X		G	A
Stephanopis sp.	X	X	X	X	C	T
Toxopidae	-	-	X	X	(G)	
Laestrygones setosa	-	-	X	X	G	T
Trochanteriidae	X	-	-	-	(G)	
Corimaethes sp.	X	-	-	-	A	T
Zodariidae	X	X	X	X	(C)	
Asteron sp.	X	-	X	X	A	T
Asteron "reticulatum"	X	X	X	X	A	T
"Australatica" sp.	X	X	X	X	A	T
Habronestes "bradleyi"	X	X	X	X	A	T
Habronestes sp.1	X	X	-	X	A	T
Habronestes sp.2	X	X	X	X	A	T
Neostorena sp.1	X	X	X	X	A	T
Neostorena sp.2	-	X	X	-	A	T
Nostera sp.	-	X	X	X	A	T
Zoridae	X	X	X	X	(C)	
Argoctenus sp.	X	X	X	X	A	T
Hestimodema sp.	X	X	X	X	A	T
Odo sp.	X	X	X	X	A	T
Thasyraea sp.	-	X	X	X	A	

Table 2 : Numbers of taxa in total and at each location and at each site. The number of species unique to each location and site is indicated in parentheses.

	Total	Waterhouse Point		Eddystone Point	
		Site 1	Site 2	Site 3	Site 4
Families	33	29		28	
		27	28	25	26
Genera	97	84		79	
		66	69	65	71
Species	130	112 (21)		109 (18)	
		88 (6)	91 (8)	87 (6)	91 (5)

Birds of Northeast Tasmania

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Abstract

An early account of Emu-wrens (*Stipiturus malachurus*) and their marshland habitat in the Scottsdale district is given in the writings of Arthur W. Swindells and Jane Ada Fletcher. Much of this habitat and other tracts of native vegetation have long since been cleared for agricultural development, resulting in changes to the composition of the avifauna. About 160 species of birds, living in a variety of habitats ranging from the adjacent seas to the mountains, occur in the Northeast and are briefly discussed. They comprise about 50% of all species recorded from Tasmania and about 20% of all Australian species. Species abundance is a result of habitat diversity and creates a most interesting range of avifauna. The region does not include any special areas upon which particular species are solely dependent for survival, and although some populations have declined due to land clearing and wetland drainage, others, such as those requiring a grassland habitat, have increased. Birds totally dependent upon the shoreline and small coastal islands are especially vulnerable to human intrusion. Critical areas of shoreline should be defined and steps taken in an endeavour to limit unwarranted and destructive interference.

Introduction

My first-hand knowledge of Tasmania's Northeast is limited to about the last forty years and has been less extensive than I would have liked; the region is indeed most interesting and important for the study of many subjects of natural history. Some early accounts of bird-life of the region were related to me by an old friend, Hobart ornithologist Arthur W. Swindells, who was an egg-collector in the first quarter of this century. Swindells studied birds and collected egg-clutches in the Bridport – Springfield area, often in association with Miss Jane Ada Fletcher, a school teacher and author of children's books as well as papers on natural history, and the Misses Olive and Isabel Lowther of Springfield. Following is one of the many accounts concerning their observations of the habits of the secretive little Southern Emu-wren (*Stipiturus malachurus*), which was once common in the then-larger wetlands of the region. It was recorded by Swindells as part of the detailed data associated with specimens in his meticulously prepared and preserved oological collection.

'Waller's Flat, Brid River, near Springfield, 15th. October, 1915: – Waller's Flat is a big marshy area bordering the Brid River, and is the haunt of several pairs of Emu Wren and Lewin's Rail. A fair sized creek flows through the swamp. In beating up the bog we flushed a male Emu-wren who, presumably, called up his mate. It was a difficult task to keep track of them amongst the cutting-grass and rushes, and several times we lost sight of them altogether. Eventually the female was observed sneaking away on her own, and after a long trail over the swamp we succeeded in trailing her to the nest, well hidden in the centre of a sword grass, surrounded by deep bog.'

In her personal letters to Swindells, Miss Fletcher related many of her birding excursions and sometimes described her encounters with snakes, which were plentiful in the extensive boggy marshes choked with decaying logs and tree-ferns. These marshes were the relict, stark reminders of the once-dense wet forests which formerly flourished on the rich soils of the area. Much of that forest, along with the marshes, have long since been cleared and drained for intensive farming.

In 1911 Miss Fletcher observed what she believed to be the Golden-headed Cisticola (*Cisticola exilis*) in the Springfield district and had received several accounts of the birds nesting amongst the tussocky grass (Fletcher 1913). This species has not since been recorded from the Tasmanian mainland.

Several years prior to 1914 Miss Fletcher, in company with her sister, travelled from Springfield to Bridport by bicycle to study the bird life there, noting along the way the presence of Forty-spotted Pardalotes (*Pardalotus quadragintus*) and a pair of Azure Kingfishers (*Alcedo azurea*) at Bridport (Fletcher 1915). As a result of these experiences and discussions with Arthur Swindells it was decided that the Great Forester River and the associated vast region of flooded tea-tree country warranted further investigation. In the autumn of 1914, Fletcher and Swindells, with the use of a dinghy, explored an area of the river east of Bridport, finding there a breeding colony of Great Cormorants (*Phalacrocorax carbo*) and Little Black Cormorant (*Phalacrocorax sulcirostris*), the nests having been built in dense tea-trees overhanging the water (Fletcher 1915).

Fletcher and Swindells also suspected the Blue-billed Duck (*Oxyura australis*) was then breeding on the shores of the Forester River (A.W. Swindells, pers. comm.). Much of this tea-tree forest was subsequently cleared for agriculture, thus making the area no longer suitable as breeding habitat for these birds.

Following the Second World War land development was

further intensified and extensive tracts of country east of Bridport were cleared for soldier settlement blocks. Other parts of the Northeast were also gradually cleared by private developers. All these agricultural pursuits, together with some more limited land clearing over perhaps 150 years, progressively changed habitats in significant areas of the region. Little is known of the fauna which would have lived in the region last century but undoubtedly the populations of many forest and wetland-dependent species would have declined as their required habitats were removed. Concomitantly, ground-feeding species such as lapwings, pipits and others requiring grasslands and semi-open habitats would have, no doubt, expanded their range. Despite the habitat changes which have occurred the Northeast of Tasmania with its wide range of habitat types, from the ocean to the mountains, supports, in varying degrees of abundance, most species of birds commonly found in Tasmania.

Seabirds

The seas over the continental shelf are not well known ornithologically, primarily because of the lack of competent, sea-faring bird-observers, but they are rich in oceanic species, included amongst which are eight kinds of albatrosses that visit the Northeast when not engaged in breeding. About thirty species of fulmars, petrels and shearwaters may also be found here, most as summer visitors from subantarctic regions. Fairy Prions (*Pachyptila turtur*) and Short-tailed Shearwaters (*Puffinus tenuirostris*) breed in abundance on some of the small coastal islands, as do Little Penguins (*Eudyptula minor*), Black-faced Cormorants (*Phalacrocorax fuscescens*) and Australian Pelicans (*Pelecanus conspicillatus*). Pacific Gulls (*Larus pacificus*), Silver Gulls (*Larus novaehollandiae*) and up to three species of terns also breed on off-shore islands. The Australasian Gannet (*Morus serrator*), which once bred on Cat Island, is a regular visitor from its breeding islands in western Bass Strait and south of the Tasmanian mainland. The Great Skua (*Catharacta skua*) is a regular annual visitor from Macquarie Island, and two species of jaegers, which breed in high Arctic regions, also visit seasonally.

Shorebirds

The tidal flats and edges of coastal lagoons are the principal habitats and feeding zones of some of the many species of migratory waders which annually visit Australia, most from breeding grounds in high Arctic regions. Up to about fifteen species, in varying abundance, might be found in northeast Tasmania during the austral summer. The migratory Double-banded Plover (*Charadrius bicinctus*), which breeds in New Zealand, over-winters on parts of the northeast Tasmanian coast. A brief account of the wader grounds at Cape Portland is given by Wall and Thomas (1967). Non-migratory, locally breeding waders also live in the region, most with strong populations. These are the Pied Oystercatcher (*Haematopus longirostris*), Sooty Oystercatcher

(*Haematopus fuliginosus*), Masked Lapwing (*Vanellus miles*), Banded Lapwing (*Vanellus tricolor*), Hooded Plover (*Thinornis rubicollis*) and Red-capped Plover (*Charadrius ruficapillus*).

Wetland birds

On the rivers and lagoons of the Northeast can be found three species of grebes, three species of cormorants, occasional egrets, the Australasian Bittern (*Botaurus poiciloptilus*), Black Swan (*Cygnus atratus*) and about ten species of ducks. The endemic Tasmanian Native Hen (*Gallinula mortierii*), Purple Swamphen (*Porphyrio porphyrio*) and Lewin's Rail (*Dryolimnas pectoralis*) also inhabit the wetlands, as does Latham's Snipe (*Gallinago hardwickii*). The Cape Barren Goose (*Cereopsis novaehollandiae*) has recently expanded its range from the Furneaux Islands to the coast of northeast Tasmania.

Landbirds

Amongst the raptorial birds are eagles, hawks, falcons and owls, eleven species of which breed in the Northeast. The Painted Button-quail (*Turnix varia*) and Brown Quail (*Coturnix ypsilophora*), occur in the heathlands, scrubs and grasslands, the Brown Quail being most abundant on some islands in the Furneaux Group. The Stubble Quail (*Coturnix pectoralis*) occurs on Flinders Island (Green 1969). Both species of bronzewings (*Phaps* spp.), which feed on the ground in clearings beneath forests and scrubs, breed locally. The nomadic Yellow-tailed Black Cockatoo (*Calyptorhynchus funereus*) has a wide distribution and no doubt is a local breeder. The endemic Green Rosella (*Platycercus caledonicus*) is a common breeding species and the sedentary Eastern Rosella (*Platycercus eximius*) and migratory Blue-winged Parrot (*Neophema chrysostoma*) breed locally in woodland areas. The Musk Lorikeet (*Glossopsitta concinna*) and migratory Swift Parrot (*Lathamus discolor*) are regular visitors if not local breeders. Four species of migratory cuckoos, all brood-parasites, visit the Northeast and breed there over spring and summer. The sedentary Tawny Frogmouth (*Podargus strigoides*) and Owlet Nightjar (*Aegotheles cristatus*) are local inhabitants which live and breed in dry sclerophyll forests. Two species of Asiatic-breeding swifts pass through on their autumn migration and the introduced Laughing Kookaburra (*Dacelo novaeguineae*), a kingfisher, is now widely distributed and firmly established in the region. The beautiful little Superb Fairy-wren (*Malurus cyaneus*) occurs in most areas where scrubby shelter is adjacent to grassland, and the tiny Southern Emu-wren (*Stipiturus malachurus*), although now rare and localised, can still be found in some damp, treeless lowlands that support dense vegetation. All ten species of Tasmanian honeyeater breed in the Northeast, as does the White-fronted Chat (*Epthianura albifrons*). The Bassian Thrush (*Zoothera lunulata*) is also there and is primarily a ground-dweller which lives mainly on the floor of wet forests or beneath tea-tree scrubs along waterways. Three Tasmanian

endemics, the Brown Scrubwren (*Sericornis humilus*), Scrubtit (*Acanthornis magnus*) and Tasmanian Thornbill (*Acanthiza ewingii*), live in the wet forests. The Brown Thornbill (*Acanthiza pusilla*), Striated Fieldwren (*Calamanthus fuliginosus*) and two species of pardalotes (*Pardalotus* spp.) favour dryer areas and all breed locally in their respective habitats. All four species of Tasmanian robins breed in the region. The Spotted Quail-thrush (*Cinclosoma punctatum*) lives and nests on the ground in semi-open, dry forest. The Olive Whistler (*Pachycephala olivacea*), Golden Whistler (*P. pectoralis*) and, Grey Shrike-thrush (*Colluricincla harmonica*) are common breeders in the sclerophyll forests, as are the migratory Satin Flycatcher (*Myiagra cyanoleuca*) and Grey Fantail (*Rhipidura fuliginosa*). The Black-faced Cuckoo-shrike (*Coricina novaehollandiae*) and Dusky Woodswallow (*Artamus cyanopterus*), both trans-Bass Strait migrants, arrive in spring and breed in dry forests. The sedentary Grey Butcherbird (*Cracticus torquatus*), Australian Magpie (*Gymnorhina tibicen*) and Forest Raven (*Corvus tasmanicus*) favour the somewhat open, dry forests. The migratory Welcome Swallow (*Hirundo neoxena*) and Tree Martin *(H. nigricans)* arrive in spring and breed during the warmer months. Richard's Pipit (*Anthus novaeseelandiae*), a resident breeding species, inhabits the native grasslands. The Silvereye (*Zosterops lateralis*), a partial migrant, is common in most habitats within the region, while the only native weaver-finch of Tasmania, the Beautiful Firetail (*Stagonopleura bella*), is a resident of the sclerophyll forests and tea-tree scrubs. The Black Currawong (*Strepera fuliginosa*) occurs on Flinders Island (Green 1969) and other islands in the Furneaux Group but is very rarely found in the lowlands of the Tasmanian mainland. There its place is occupied by the Grey Currawong (*Strepera versicolor*) which is not uncommon in the Northeast.

Introduced European species include the Skylark (*Alauda arvensis*), House Sparrow (*Passer domesticus*), European Goldfinch (*Carduelis carduelis*), European Greenfinch (*C. chloris*), Common Blackbird (*Turdus merula*) and Common Starling (*Sternus vulgaris*), all of which are firmly established and breed locally.

Summary

This series of notes has covered species that are either permanent residents, regular migrants that breed locally, visiting migrants that breed elsewhere, or simply transient species that occur regularly. It represents about 50% of all birds ever recorded from Tasmania, including rare vagrants, and is about 20% of species recorded for the whole of Australia. This is a most impressive list, and reflects the rich and diverse range of habitat types in northeast Tasmania, and the associated diversity of avifauna in the region.

The Northeast does not include any areas upon which survival of a particular species is critically dependent, and although some species have declined due to land clearing

and habitat alteration, others, such as those that benefit from grassland expansion, have increased. The rugged terrain of much of the inland has protected extensive areas of natural vegetation from human exploitation, and thus protected much of the native avifauna.

I do not envisage a significant threat to the continuing presence of any species in the region, with the possible exception of those dependent upon the narrow intertidal belt. Beaches, in particular, are being increasingly subjected to human recreational activity, often involving motorbikes, off-road vehicles and dogs, resulting in serious disturbance of birds dependent upon such areas for breeding and feeding. These comments apply equally to some of the more easily accessible off-shore islands upon which terns, petrels, pelicans, and other seabirds also depend for breeding. These small islands often attract the attention of interested day-visitors, especially when birds are nesting, and the intrusion can create a serious disturbance. This is a national problem, and just as we are now realising the importance of protecting the remnant rainforests and heathlands for habitat and species conservation, so, surely, we should be looking more seriously to the protection of at least some areas of special seabird breeding habitats and feeding regions on shorelines and intertidal zones, for the very same reasons. It therefore seems appropriate that an assessment be undertaken to define critical areas of shoreline habitat. Where considered necessary, actions should be implemented in an endeavour to limit activities which might be detrimental to populations of those birds which have, for countless generations, been dependent upon these relatively small and finite areas for their breeding.

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Mammals of Northeast Tasmania

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Abstract

Of the 35 native mammals in Tasmania, only the broad-toothed rat has not been recorded from the Northeast. The region contains most of the remaining Tasmanian range of the New Holland mouse, as well as major parts of the ranges of the Tasmanian bettong and forester kangaroo. The patchy nature of land clearance has created a mosaic of bush and pasture that has benefited most of the larger herbivores together with the Tasmanian devil, eastern quoll and eastern barred bandicoot. For other species, land clearance has resulted in a decline in numbers through loss of habitat. The New Holland mouse has suffered a major decline through destruction of its heathland habitat. The forester kangaroo has also undergone a major decline in its range through over-hunting and habitat loss. However, with the possible exception of the thylacine, no species has become extinct in northeast Tasmania. The region continues to support a diverse and abundant mammal fauna, probably reflecting the high diversity of habitats.

Introduction

Northeast Tasmania is topographically, climatically and geologically diverse. Moreover, this diversity is found in a relatively small area. As a result the Northeast supports a high diversity of habitats for mammals, including alpine moorlands and heath, temperate rainforest, wet sclerophyll forest, dry sclerophyll forest, grassy forests and woodlands, and coastal heathlands (Kirkpatrick 1991). Buttongrass moorland, while present in the region, is very limited in distribution and is highly fragmented (Jarman et al. 1988). Land cleared for agriculture is patchily distributed and in total represents less than 25% of the region. State forest covers a further 41% of the Northeast while less than 5% of the region is protected in reserves (Williams 1989).

This paper examines the mammal fauna of northeast Tasmania and considers its distinctive features as well as the possible impact of European settlement on this fauna.

Sources of information

Historical records are limited in number and they focus on those species that were either pests or exploited as food or skins. Among the earliest of these records are those of G.A. Robinson, who travelled around Tasmania, including the Northeast, during the period 1829-34 (Plomley 1966). Robinson made numerous observations on those species hunted for food such as the forester kangaroo and Bennett's wallaby. Other historical records are contained in Gunn (1852), Lord (1927), Steele (1934), Smith (1980) and Guiler (1982, 1985). In more recent times, surveys of mammals have been carried out at a number of locations in the Northeast. These include those of Green (1967, 1979), Norton (1983), Hocking (1980), Pye (1991) and Taylor et al. (1987). The Tasmanian Parks and Wildlife Service (PWS) regularly surveys the region by systematic spotlighting (Driessen & Hocking 1992) and roadkill surveys, and PWS carried out an intensive

survey of the Waterhouse area in November 1993. This information, together with other records provided by the public and government agencies, has been entered in the TASPAWS Wildlife Atlas operated by the PWS. Results were recently published as presence/absence records on 10 x 10 km grid maps in Rounsevell et al. (1991). The following species accounts are based largely on these distribution maps.

Mammal species of Northeast Tasmania

A list of native mammal species recorded from the Northeast is given in table 1 together with information on their abundance and distribution, and the net effect of human settlement on their conservation status.

Native species

1. Monotremes

Family Ornithorhynchidae

The platypus, *Ornithorhynchus anatinus* (Shaw, 1799), is a common inhabitant of major river systems in northeast Tasmania. It is also commonly found in farm dams on agricultural land where its tunnelling activities occasionally threaten dams and water races (Steele 1934). In the 1800s, the platypus was hunted for its high-quality fur, and until the 1960s it was accidentally killed in nets set in streams for eels. Pollution of streams continues to be a threat to local platypus populations.

Family Tachyglossidae

The echidna, *Tachyglossus aculeatus* (Shaw, 1792), is widespread and common in northeast Tasmania. It occurs in most vegetation types although it is most often recorded in dry sclerophyll forest where the ants upon which it feeds are most abundant. It is frequently seen in agricultural areas.

Table 1. Native mammal species in northeast Tasmania.

Abundance: A = abundant, C = common, LC = locally common, O = occasional, P = present.
Tasmanian distribution: E = east, NE = Northeast, T = Statewide
Human impact on status: + = positive, - = negative.

	Abundance	Tasmanian distribution	Human impact on status
Monotremes			
Platypus	C	T	-
Echidna	C	T	-
Marsupials			
Swamp antechinus	O	T	-
Dusky antechinus	LC	T	-
Spotted-tailed quoll	O	T	-
Eastern quoll	LC	T	+
Tasmanian devil	C	T	+
Thylacine	Possibly Extinct	T	-
White-footed dunnart	O	T	-
Brown bandicoot	LC	T	-
Barred bandicoot	LC	E	+
Wombat	C	T	+
Sugar glider	O	T	-
Ringtail possum	C	T	-
Brushtail possum	A	T	+
Little pygmy possum	O	T	-
Eastern pygmy possum	O	T	-
Tasmanian bettong	LC	E	-
Long-nosed potoroo	C	T	-
Tasmanian pademelon	A	T	+
Bennett's wallaby	A	T	+
Forester kangaroo	Rare	NE	-
Eutherians			
Gould's wattled bat	P	E	-
Chocolate wattled bat	P	T	-
King River eptesicus	P	T	-
Large forest eptesicus	P	T	-
Little forest eptesicus	P	E	-
Great pipistrelle	P	E	-
Lesser long-eared bat	P	T	-
Gould's long-eared bat	P	E	-
Water rat	LC	T	+
Long-tailed mouse	LC	T	-
New Holland mouse	Rare	NE	-
Velvet-furred rat	C	T	-

2. Marsupials

Family Dasyuridae

The Tasmanian devil, *Sarcophilus harrisii* (Boitard, 1841), is widespread and abundant throughout northeast Tasmania. It occurs in all major vegetation types but is most abundant in pastoral country where large numbers of dead wallabies and stock provide abundant carrion for this scavenger (Guiler 1970). Devil numbers underwent a major decline throughout Tasmania around the turn of the twentieth century and remained low until the 1960s (Guiler 1982). They are currently increasing (Driessen & Hocking 1992).

The eastern quoll or native cat, *Dasyurus viverrinus* (Shaw, 1800), is widespread and locally common over much of Tasmania including the Northeast. It has apparently benefited from land clearance and is often seen in large numbers in agricultural areas where it feeds on pasture insects (Blackhall 1980). By comparison, the tiger cat or spotted-tail quoll, *Dasyurus maculatus* (Kerr, 1792), is widespread throughout forest and coastal scrub in the Northeast, but is nowhere common. Clearing for agriculture has resulted in a loss of habitat, although the Northeast remains a major stronghold for this species.

The swamp antechinus, *Antechinus minimus* (Geoffroy, 1803), has a very limited and patchy distribution within the region, being more commonly associated with extensive areas of buttongrass moorland in west Tasmania. In the Northeast it has been recorded from wet gullies, heaths and swamps and some loss of habitat has resulted from land clearance for agriculture. The dusky antechinus, *Antechinus swainsonii* (Waterhouse, 1840), occurs in wet sclerophyll forest and rainforest in the higher rainfall areas of the Northeast. As with the previous species, some loss of habitat has resulted from land clearance for agriculture. The white-footed dunnart, *Sminthopsis leucopus* (Gray, 1842) has been recorded widely but infrequently across Tasmania including the Northeast. It occupies a variety of vegetation types including rainforest, sclerophyll forest and heathland.

Family Thylacinidae

The decline and likely extinction of the Tasmanian tiger or thylacine, *Thylacinus cynocephalus* (Harris, 1808), is well documented (Smith 1980, Guiler 1985). The Northeast was one of the strongholds of its former distribution and alleged sightings continue to be reported in the region. Steele (1934) wrote that the thylacine once roamed all over the Portland Municipality and that nine were observed in the Anson Marshes in 1882. By 1934 it was no longer known from the area. Guiler (1985) states that there was a large concentration of thylacines centred around the northeast Tasmanian highlands. Smith (1980) records that a large proportion of bounty payments were made in the Northeast. He also found that a significant proportion of all road sightings of the thylacine between

1936 and 1980 were on the Tasman Highway, particularly in the Sideling and Weldborough areas of the Northeast.

Family Peramelidae

The southern brown bandicoot, *Isoodon obesulus* (Shaw, 1797), is widespread and locally common throughout Tasmania, including the Northeast. It occurs in heathland and dry forest as well as on agricultural land where its diet includes pasture insect pests.

The eastern barred bandicoot, *Perameles gunnii* Gray 1838, was originally recorded from native grasslands and grassy forests in the Midlands and Southeast (Hocking 1990). While this habitat has been largely destroyed by clearing and grazing the species has adapted successfully to agricultural land and has extended its range into parts of the Northwest, Southeast and Northeast that previously supported unsuitable wet forest habitat (Driessen et al. 1996). It is locally abundant on agricultural land in these areas.

Family Vombatidae

The common wombat, *Vombatus ursinus* (Shaw, 1800), is widely distributed and common in the Northeast, particularly in sandy coastal areas adjacent to improved pasture. Farmers in these areas occasionally cull wombats to prevent pasture and fence damage. There has been a small but steady increase in the abundance of this species in the Northeast over the last 20 years which presumably is related to the increase in the area of pasture adjacent to native forest (Driessen & Hocking 1992). Lord (1927) reported that wombats from Flinders Island were liberated at Eddystone Point by the lighthouse keepers.

Family Phalangeridae

The brushtail possum, *Trichosurus vulpecula* (Kerr, 1792), is widespread and abundant throughout most of Tasmania including the Northeast. The species is most abundant on agricultural land which still carries adequate bush shelter for nest sites, and in such areas possums can cause significant crop damage. This species has traditionally supported a fur industry (Steele 1934, Guiler 1957) which as recently as 1980 harvested up to 300 000 skins annually of which some 20 000 are estimated to have come from the Northeast (PWS records). This harvest has declined in recent years due to a decrease in the demand for fur skins and brushtail possum numbers have been steadily increasing as a result (Driessen & Hocking 1992).

Family Petauridae

The ringtail possum, *Pseudocheirus peregrinus* (Boddaert, 1795), is widespread and common throughout Tasmania. It is most common in dense stands of tall tea tree (*Melaleuca* spp. or *Leptospermum* spp.) along watercourses and in swamps in forest and on agricultural

land. Ringtail possums were very abundant earlier this century, and like the brushtail possums, supported a significant fur industry (Guiler 1957). Populations declined in the 1950s, probably due to disease (Green 1973), and have only recovered in recent years.

The sugar glider, *Petaurus breviceps* Waterhouse 1839, is widespread but only patchily distributed through sclerophyll forest communities in the Northeast. Forestry activities that result in a loss of nesting hollows or nectar-producing understorey species are likely to affect this species adversely (Henry & Suckling 1984). The sugar glider is believed to have been introduced to Tasmania and a number of animals from mainland Australia are known to have escaped captivity in the Launceston area between 1834 and 1839 (Gunn 1852). However, Troughton (1957) questioned this belief on the basis of the wide distribution of the species in Tasmania including the extreme south and Tasman Peninsula. The species is not known from the Tasmanian fossil record (Green 1973).

Family Burramyidae

Both the eastern pygmy possum, *Cercartetus nanus* (Desmarest, 1818), and the little pygmy possum, *C. lepidus* (Thomas, 1888), occur widely across Tasmania, including the Northeast, although both species are only occasionally recorded. The eastern pygmy possum is generally found in wet sclerophyll forest while the little pygmy possum is more frequently recorded in dry sclerophyll forest and heath. Both species have suffered habitat loss from land clearance for agriculture.

Family Potoroidae

The long-nosed potoroo, *Potorous tridactylus* (Kerr, 1792), is widespread throughout Tasmania including the Northeast and is locally common in forest where there is dense undergrowth. The species has lost some habitat to land clearance.

The Tasmanian bettong, *Bettongia gaimardi* (Desmarest, 1822), is restricted to east Tasmania. It is widespread in lowland areas of the Northeast where it occurs in dry sclerophyll forest and woodland with an open understorey on poor-quality soils. The species is known to persist in areas that have been planted with *Pinus radiata*. It has, however, lost habitat to land clearance for agriculture. Bettong habitat is poorly represented in conservation reserves (Driessen et al. 1990).

Family Macropodidae

The forester or eastern grey kangaroo, *Macropus giganteus* Shaw 1790, has undergone a massive reduction in numbers and now occurs in less than 10% of its original range. At the time of European settlement the forester ranged throughout east and central Tasmania including the Northeast (Lord 1927, Barker & Caughley

1990). It reached its highest densities in the coastal areas of the Northeast and in some of the east Tasmanian river valleys, notably those of the Macquarie and South Esk (Barker & Caughley 1990). Robinson (Plomley 1966) frequently recorded the species during his wanderings in the coastal parts of the Northeast. By the early 1900s, as a result of hunting and to a lesser extent land clearance, the species was in decline. Lord (1927) noted that the Northeast was one of the species' remaining strongholds, although even there the advance of settlement was having its effect. Steele (1934) wrote that the forester had been considerably depleted even in the Northeast. By the 1960s the forester kangaroo had been reduced to three isolated populations, two of which were in the Northeast, and it was regarded as threatened and in urgent need of reservation (Burbidge 1977). Since that time the status of the species has been improved through a re-establishment program and the reservation of over 10 000 ha of forester kangaroo habitat in Mt William National Park. The Northeast remains the stronghold of the species.

Bennett's wallaby, or the red necked wallaby, *Macropus rufogriseus* (Desmarest, 1817), and the Tasmanian pademelon, *Thylogale billardierii* (Desmarest, 1822), are widespread and abundant throughout Tasmania, including the Northeast. Bennett's wallabies are more common in drier, more open vegetation types and pademelons in wetter, denser vegetation, although both species are most abundant where bush occurs adjacent to pasture. Both species have a long history of being hunted for meat, skins or sport (Plomley 1966, Guiler 1957). However, unlike the forester neither species declined in numbers. Indeed, in recent times the abundance of both has been promoted by the mosaic pattern of pasture development in northeast Tasmania together with a decline in hunting (Driessen & Hocking 1992).

3. Eutherians

Family Vespertilionidae

The distributions and habitats of the eight bat species in Tasmania are poorly known (Taylor et al. 1987). All eight species have been recorded in the Northeast and it is likely that they are all well-distributed in the region (table 1).

Family Muridae

The water rat, *Hydromys chrysogaster* Geoffroy 1840, is widely distributed in aquatic habitats throughout northeast Tasmania as well as the rest of the State. It occurs in artificial water impoundments and has probably benefited from their construction. The species was once hunted for its pelts. Hunting reached its peak during the 1940s but declined thereafter due to lack of demand (Guiler 1957). The hunting of this species has not been permitted since 1974.

The velvet-furred or swamp rat, *Rattus lutreolus* (Gray,

1841), is one of the most abundant and widespread mammals in Tasmania and has been recorded in a wide range of vegetation types from lowland to alpine areas. Although the species is common and well-distributed in native habitat in the Northeast, clearance of land for agriculture has reduced its range in historic times. Over-grazing and firing, both of which reduce ground cover, have also reduced the available habitat for this species (Green 1967).

The most recent addition to Tasmania's native mammal fauna occurred in the Northeast with the discovery of the New Holland mouse, *Pseudomys novaehollandiae* (Waterhouse, 1843), in heathy woodland at The Gardens, north of St Helens, in 1976 (Hocking 1980). The largest part of its known range remains in the Northeast despite deliberate searches for the species in similar habitats outside the region. The species is restricted to coastal heathlands and woodland with sparse ground-cover on sand or siliceous soils. The area of such coastal heathlands in northeast Tasmania has been considerably reduced as a result of habitat degradation and clearance for agriculture (Kirkpatrick 1977). The New Holland mouse has been recorded from several sites within Mt William National Park.

The long-tailed mouse, *Pseudomys higginsi* (Trouessart, 1897), is widely distributed in Tasmania, being found in rainforest, wet sclerophyll forest and rock screes in mountainous areas. It is rarely recorded in dry forests, only occurring in this habitat on drainage lines and rock screes at higher altitudes. The distribution of this species in the Northeast is centred around the highlands where it is locally common in suitable habitat.

The broad-toothed mouse, *Mastacomys fuscus* Thomas 1882, is the only native mammal species which has not been recorded from the Northeast. The species is only known from a small number of locations in buttongrass moorland in the west of the State. Given the limited and patchy distribution of buttongrass moorland in the Northeast it is unlikely that the broad-toothed mouse occurs in this region.

Introduced Species

Family Muridae

Three species of introduced rodent are present in Tasmania, all of which are present in the Northeast. The house mouse, *Mus musculus* Linnaeus 1758, occurs in and around human habitations as well as in native vegetation, particularly where recently disturbed by fire. It is a potential competitor of the New Holland mouse in heathlands (Pye 1991). The black rat, *Rattus rattus* (Linnaeus, 1758), is occasionally found in disturbed sites in native bush as well as around human habitations. The brown rat, *Rattus norvegicus* (Berkenhout, 1769), is limited to towns where it is often seen around drains and sewers.

Family Cervidae

Fallow deer, *Dama dama* (Linnaeus, 1758), were introduced to Tasmania around 1830 and have since become established in the grassy forests and woodlands of the Midlands, Central Plateau and the southwest part of the Northeast. The population is currently estimated to be around 15 000 animals of which approximately 1 500 are shot by hunters each year (PWS Records).

Family Bovidae

Feral goats, *Capra hircus* Linnaeus 1758, occur in scattered herds in southeast, central north and northeast Tasmania (Howell & Atkinson 1994). They occur most often in steep, rocky and thickly vegetated country. Feral goat numbers increased through escapes and deliberate releases following the decline in the goat industry in the 1980s. Feral goats are seen as a potential threat to native vegetation and efforts are currently underway to eradicate them while this is still feasible (Howell & Atkinson 1994).

Family Leporidae

The rabbit, *Oryctolagus cuniculus* (Linnaeus, 1758), has a patchy distribution in the Northeast, occurring primarily on cleared agricultural land but extending into grassy forests and woodlands. In general, numbers have remained relatively low since the introduction of myxomatosis in the 1960s.

The brown hare, *Lepus capensis* Linnaeus 1758, is locally common in the drier grazing lands of the south and west parts of the Northeast.

Family Felidae

The feral cat, *Felis catus* Linnaeus 1758, occurs throughout the Northeast. It is both a predator on and a competitor with many native mammal species. It is also the definitive host for a protozoan parasite, *Toxoplasmosis gondii*, which when passed on to other mammals can be fatal (Lenghaus et al. 1990). There are currently no effective means of feral cat control and research on control methods is being undertaken throughout Australia.

Discussion

A total of 35 native mammals have been recorded from Tasmania (table 1). Six of these species are restricted to the State. A further 15 species are recognised as subspecies, hence 60% of the State mammal fauna is uniquely Tasmanian. Tasmania is fortunate in that most of its mammal species are relatively common and widespread. Only two species are included in the current list of rare or threatened species (Vertebrate Advisory Committee 1994): the thylacine (extinct) and the New Holland mouse (rare). A third species, the eastern barred

bandicoot, is listed as vulnerable on the national endangered species list (Kennedy 1992). Although this species is common in Tasmania, it is on the verge of extinction on the Australian mainland.

Significance of the mammal fauna of northeast Tasmania

All but one of Tasmania's 35 native mammal species have been recorded from northeast Tasmania. This is the highest diversity of mammal species for any comparably sized region of the State and reflects the variety of habitats available. However, it must be noted that the diversity of mammals in the Northeast is only marginally higher than in other regions due to the wide distribution of most of Tasmania's mammal fauna. Twenty-six species have a statewide distribution with the remaining nine species being confined largely to either the east or west of the State (Rounsevell et al. 1991). Many mammal species are particularly common in the Northeast, as a night-time drive will reveal. This is largely a result of the patchy nature of land clearance, which has provided high-quality feeding areas for herbivores and insectivores, and adjacent natural areas of cover. The increased number of prey herbivores, both native and introduced, has also contributed to an abundance of Tasmanian devils in the Northeast. The Northeast is also significant in that it contains most of the range of Tasmania's only extant rare or threatened mammal, the New Holland mouse (Vertebrate Advisory Committee 1994), and a major part of the range of both the Tasmanian bettong and the forester kangaroo.

Human impacts

Human activities undertaken in the Northeast include land clearing for agriculture, felling and regeneration of forest, use of 1080 poison and hunting. Of these, land clearance for agriculture has had the greatest impact on the native mammal fauna of northeast Tasmania. Some species have benefited from the patchy pattern of land clearance undertaken in the Northeast. These include the larger herbivores (with the exception of the forester kangaroo); the eastern barred bandicoot and the eastern quoll, both of which feed on pasture insect pests (Heinsohn 1966, Blackhall 1980); and the Tasmanian devil, which feeds on the abundant carrion from large populations of wallabies and domestic stock (Guiler 1970). However, for most mammal species in the Northeast, land clearance has resulted in a decline in numbers through loss of habitat. The impact has been greatest in the case of the New Holland mouse, which has had its heathland habitat greatly reduced by clearing (Kirkpatrick 1977).

Forestry activities are widely undertaken in the Northeast, and the felling and regeneration of native forest have great potential for impact on mammal populations. Species requiring tree hollows for shelter, such as bats, pygmy possums and sugar gliders, are most likely to be threatened by these activities (Taylor 1991). Forest plantations of pines and *Eucalyptus nitens*, whilst of more limited extent, support only a depauperate mammal fauna. Plantations do however, support bettong populations (Driessen et al. 1990).

Hunting is a traditional and widely practised activity in the Northeast. Native mammal species that have in the past been hunted for skins or meat include the forester kangaroo, Bennett's wallaby, Tasmanian pademelon, brushtail possum, ringtail possum, water rat and platypus (Guiler 1957). In addition, the thylacine, Tasmanian devil and wombat have been culled by farmers attempting to reduce a perceived threat to their stock or crops. Of these species, only the forester kangaroo and thylacine have been threatened by hunting. The other species remain widespread and common with Bennett's wallabies, Tasmanian pademelons and brushtail possums continuing to sustain high levels of harvesting in recent years.

In summary, despite the pressures associated with human settlement, the Northeast continues to support a high diversity and abundance of native Tasmanian mammals.

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Biogeographical Affinities of Macrocrustacean Groups in Northeast Tasmania

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Abstract

The biogeographical significance of the hypothesized northeast Tasmanian bioregion was tested using morphological and genetic (isozyme electrophoretic) data from three groups of malacostracan crustaceans occurring in cool and wet environments: freshwater janirid isopods, and crayfish of the genera *Engaeus* and *Astacopsis*. Two patterns emerged: species and species groups which were endemic to northeast Tasmania, and species whose nearest relatives occurred in south Victoria (predominantly southeast Victoria). Detailed distributional data for freshwater crayfish supported the concept of a faunal break in the lower reaches of the Tamar River system, exhibited some intriguing parapatric boundaries, and highlighted a 'hot spot' in the Mt Horror area. Accordingly, reservation options for biodiversity conservation need to be explored in the Mt Horror area. Evidence suggests that the northeast Tasmanian bioregion could be supported by macrocrustacean groups, but that nearest biogeographic affinities should be regarded as southeast Victoria and eastern Bass Strait islands, rather than the rest of Tasmania.

Introduction

A geographical region can be assessed for its distinctiveness by examining the similarity of its biotic assemblages or climatic or landscape features to those of nearby areas. For instance, the most recent Australia-wide treatment, an interim biogeographical regionalisation (Thackway & Cresswell 1995), recognised 80 bioregions based predominantly on landform, climate, geology/lithology, vegetation and floristics. In Tasmania seven biogeographic regions were recognised. One of these was 'Ben Lomond', encompassing all of northeast Tasmania from the Fingal Valley in the south to the Tamar Estuary in the west (but not including the islands of the Furneaux Group, which, together with Wilsons Promontory in Victoria, constitute another bioregion). The northeast Tasmanian bioregion of Ben Lomond thus defines the working area for this paper.

Another approach used in bioregional assessments is the delineation of regional endemism, where unrelated groups of taxa are together found to be restricted to a particular area (see for instance Hopper 1979; Kirkpatrick & Brown, 1984a, 1984b). Defining regions of endemism can be of practical significance for biodiversity conservation, since localised disturbances or developments can have a greater impact on restricted endemics than on widespread and common taxa, and because conservation action can be administered at a regional level (World Conservation Monitoring Centre 1992).

A focus on endemism emphasises the importance of present-day presences and absences in revealing the geographical affinities of biota. Alternative approaches have examined distributions of taxa, and asked 'Where do the closest relatives exist today?'. Thus groups of closely related taxa have their phylogenics hypothesized, and branchings of phylogenetic trees are equated to geographical vicariant events in the evolution of the group (Craeraft 1982). Biogeographic affinities can thus be based on the relatedness of taxa. Congruence, when such affinities are matched by data from two or more groups of species, is strong evidence to support any conclusions based on one group alone.

The importance of using relatedness in conjunction with distributional data is given in the following hypothetical example. Region A contains five species, all closely related and the only living examples of one endemic genus, while Region B contains five endemic species representing five genera. Region A is thus important for biodiversity conservation because it houses several examples of one genetic type found nowhere else. Region B, however, contains one example each of up to five genetic types. Which region should receive the highest priority for conservation action? The question is an important one because conservation resources and reservation possibilities are limited, and any action to conserve biodiversity should have multiple benefits. This requires the selection of taxonomic groups for their capacity to indicate relative contributions to biodiversity patterns. Relatedness, usually with the use of genetic distance data (Crozier 1992), thus plays a role in this process of determining priorities.

Ideally, therefore, an answer to the question 'Is an area biogeographically distinct, and what relevance has this to biodiversity conservation?' can be best answered by reference not only to landscape features, biotic assemblages and degrees of endemism, but also to patterns of relatedness amongst speciose groups of taxa. This paper, which examines three malacostracan macrocrustacean groups, employs all these approaches to test the distinctiveness of northeast Tasmania as a bioregion.

Methods

Macrocrustaceans are good subjects for biogeographic studies because they are relatively well known taxonomically, often with well-defined distributions. In particular, such groups contain both widespread and restricted species, with a capacity to demonstrate regional endemism in some cases.

The janirid isopods in the genus Heterias

Freshwater isopods in the family Janiridae are known to occur across southern Australia (Horwitz & Knott, unpublished data). Only three species have been described, but as part of a recent systematic review of the group an isozyme electrophoretic study was undertaken. This study examined 30 populations from across the group's geographical range at up to 19 enzyme loci. The study included eight sites from south Victoria, one site from north New South Wales, two sites from near Perth in Western Australia, and 15 sites from Tasmania (of which two were from northeast Tasmania). Patterns of relatedness were determined from distance data based on allelic fixed differences using Unweighted Paired Group Mean Averaging (UPGMA). For the purposes of this paper only the relationships found for the two northeast Tasmanian populations have been presented. A full report of this study is in preparation by J. Andrew, B. Knott and the author.

The freshwater crayfish in the genus Astacopsis

This genus is found throughout Tasmania where three species are currently recognised (Hamr 1992): *A. gouldi* (the giant Tasmanian freshwater lobster) from northwest and northeast Tasmania, *A. franklinii* from northeast, southeast and west Tasmania, and *A. tricornis* from northwest and central Tasmania. Species in the genus are most similar to those in the genus *Euastacus* in both their morphology and their ecological requirements. Most of these crayfish are spiny and require cool, clear, flowing waters in well-shaded creeks and rivers, but they are also known to burrow under banks, rocks, and logs and in organic-rich soils, where their burrows are often laterally extensive. Distributional and morphological data collected for *Astacopsis* spp. (Swain et al. 1982; Horwitz 1994) and *Euastacus* spp. (Morgan 1983, 1986) are used in this paper.

The freshwater crayfish in the genus Engaeus

A review of the systematics of freshwater crayfish in this group revealed 35 species distributed in southeast Australia (Horwitz 1990a, 1995), including eight species from northeast Tasmania. A feature of the group was the restricted distributions of a number of the taxa; in particular, several species have such narrow ranges that they warrant concern from a conservation viewpoint (Horwitz 1990b). A study of one such species, *Engaeus spinicaudatus* from the Scottsdale area, provided fine-scale distributional data for the genus in northeast Tasmania (Horwitz 1991), allowing an assessment of endemism, sympatry and parapatry (or 'faunal breaks' *sensu* Mesibov 1994). Patterns of relatedness for the group have been determined from electrophoretic data (Horwitz et al. 1990) and morphological data (Horwitz 1990a), as shown in Table 1. Thus, for each species found in northeast Tasmania, its phylogenetic affinities could be hypothesized and its distribution compared with that of its nearest extant relative.

Results

Janirid Isopods

The data collected for this group, although of a preliminary nature (only 26 sites were analysed from across southern Australia, revealing more than 30 electromorphs, representing at least that many species), indicates a high level of genetic variability within the group. The data could not be interpreted to reveal the total number of species, nor the species boundaries across the group's geographical range. This is best exemplified by the fact that a high degree of fixed differences was found to exist between populations, and relatively few of the populations could be deemed conspecific. Indeed the results showed that the group is composed of what appear to be numerous geographically restricted taxa. The two northeast Tasmanian populations were so different from each other and from other populations sampled that their phylogenetic affinities could not be ascertained. By inference, it might be hypothesized that both represent a proportion of the group that evolved in the Northeast over a much longer period of time, leading to regional endemism.

Astacopsis

A. gouldi has a range which includes northeast and northwest Tasmanian metapopulations. Evidence for the degree of relatedness between these two is not available, but is urgently required for management purposes (Horwitz 1994). There is a clear disjunction between northeast and northwest Tasmanian occurrences; they are separated by the Tamar drainage system from which the species is apparently absent. This abrupt pattern mimics that found for another large freshwater organism, the blackfish *Gadopsis marmoratus*, prompting early students of Tasmanian biogeography to ponder what environmental influences have operated in the Tamar system to exclude them (see for example Gould 1870).

At the supraspecific level, it appears at first glance that all *Astacopsis* species should be more closely related to each other than they are to any other crayfish taxa. However, the morphological characteristics which are traditionally used to distinguish the genus *Astacopsis* from *Euastacus* are unreliable. *Astacopsis* is separated from Euastacus on the basis of two or three characters: the calcareous/membranous nature of the telson, the form of

the stem of the podobranch gills (Clark 1936, Riek 1969), and the spination of the abdomen (Clark 1936). The spination of the abdomen displayed by *Astacopsis* species is encompassed by the variation of spination shown by *Euastacus* species. The membranous nature of the posterior portion of the telson varies in both genera according to the species examined, and to the sex, age and moult stage of the individual; the transverse suture on the telson can be obsolete in *Euastacus* or faint in *Astacopsis*. Cursory examination of the podobranch in the species *Astacopsis franklinii* by the author has suggested that variability in the form of the stem exists throughout its geographic range. Therefore, the two genera may not form natural groupings as the existing taxonomies suggest. Instead, the biogeography of species in this malacostracan group could be considered to form an eastern Australian continuum stretching from Tasmania in the south to Cape York in the north.

The resolution of phylogenetic affinities within the *Astacopsis-Euastacus* group in future studies will determine new supraspecific taxonomies. Of the species which occur in northeast Tasmania, the affinities of *A. gouldi* are unclear at present, but *A. franklinii* appears to share closer relationships with *Euastacus woiwuru* and *E. neodiversus* (both from South Gippsland) than it does to either of the two other Tasmanian species. This conclusion is based on the only phylogenetic data available for the group, namely a dichotomous key for the genus *Euastacus* provided in Morgan (1983). If specimens of *A. franklinii* are tested through the key they can be classified as either of the two *Euastacus* species. This analysis assumes that the dichotomous key, based on a detailed documentation of the geographical variation of morphological characteristics in the genus *Euastacus*, contains sufficient phylogenetic information to be useful in this regard. The two other Tasmanian species have quite different endpoints in the key, reinforcing the notion that species in the genus *Astacopsis* may be polyphyletic.

Engaeus

The distributions of species in this genus in northeast Tasmania are given in figures 1 and 2.

E. laevis is known from two locality clusters in northeast Tasmania in coastal lowland areas (fig. 1), and conspecific populations occur in east Victoria, from lowland parts of the Latrobe River basin to the Mallacoota region near the Victoria-New South Wales border. This distribution pattern demonstrates the close affinities of northeast Tasmania with southeast Victoria. At the supraspecific level its nearest relative appears to be *Gramastacus* (table 1) from west and north Victoria.

E. cunicularius occurs in coastal regions around Bass Strait (predominantly on the Bass Strait islands and in south Victoria), including coastal populations around Waterhouse, Mt William and near the Asbestos Range (fig. 1). Possible mechanisms leading to such a distribution, involving the fluctuations of sea levels during glacial and interglacial periods, have been given in Horwitz (1988). The hypothesized nearest relative of *E. cunicularius* (table 1) is *E. quadrimanus* from southeast Victoria.

E. mairener is found across the lowland portion of northeast Tasmania from the Ansons River area to near Port Sorell, west of the Tamar system (fig. 1). Electrophoretic results for Tasmanian species (Horwitz et al. 1990) demonstrate that it belongs to a species group of three, with two other Tasmanian species: *E. uulloporius* from the Meander River valley to the Mt Barrow foothills, and *E. granulatus* from an area east and south of Port Sorell (fig. 1). Whilst *E. mairener* is found predominantly within the Ben Lomond bioregion, neither it nor its closest relatives are endemic to it. This appears to reflect a westerly extension of the Ben Lomond bioregion. The disjunct nature of the distribution of *E. mairener* (fig. 1) may be the result of insufficient sampling, or may provide evidence for the faunal break referred to by Mesibov (1994) as the Bridport Gap.

Of the remaining four endemic species found on the northeast Tasmanian mainland (fig. 2), *E. orramakunua* (from the Mt Arthur area), and *E. leptorhynchus* appear to be closely related, and to be related to *E. martigener* from upland areas of the Furneaux Group, *E. australis* from Wilsons Promontory and *E. orientalis* from east Victoria and southeast New South Wales (table 1). This species grouping remains a hypothesis in need of testing by more rigorous phylogenetic means.

E. tayatea and *E. spinicaudatus* have uncertain phylogenetic placements within the genus (table 1). Both occur in the Mt Horror area of northeast Tasmania (figs 2, 3).

A detailed examination of *Engaeus* distributions near Mt Horror reveals a complex interplay of sympatric, allopatric and parapatric occurrences of five species (Fig. 3). *E. mairener* is found throughout the area and occurs in sympatry with *E. leptorhynchus, E. tayatea,* and *E. spinicaudatus*. Clear microhabitat separation was usually evident, with *E. mairener* close to flowing water in the creek channel and the three other species at some distance from the creek. Apart from sites of sympatry between *E. spinicaudatus* and *E. tayatea* in the extreme northern parts of the *E. spinicaudatus* range, no other sympatries exist in the area. From figures 1, 2, and 3, parapatric boundaries can be hypothesized for *E. spinicaudatus* and *E. leptorhynchus*, and for *E. tayatea* and *E. leptorhynchus* (extending in a line northeast - southwest). Allopatric separations which might turn out to be parapatric given more detailed sampling include those between *E. spinicaudatus* and *E. cunicularius* (fig. 3) and *E. leptorhynchus* and *E. orramakunua* (fig. 2). Further details of habitat utilisations of the five species in the Mt Horror area are given in Horwitz (1991).

Table 2 summarizes the implications of distribution and relatedness for biodiversity conservation. Two species are formally regarded as being threatened in northeast Tasmania: *E. spinicaudatus* and *E. orramakunna* (Invertebrate Advisory Committee 1994). The latter species belongs to a clade that is represented by at least four other species; two of these, *E. martigener* and *E. australis*, are regarded as rare and therefore of conservation concern (Horwitz 1995), although both are well reserved (in Strzelecki National Park on Flinders Island, and in Wilsons Promontory National Park in Victoria, respectively). The other two species (*E. orientalis* from East Gippsland and *E. leptorhynchus*) have relatively wide geographical ranges. Given these data it is possible to infer that the clade is not currently vulnerable to extinction, although individual species within it may be.

The restricted distribution of *E. spinicaudatus* from the Great Forester River valley between Mt Stronach and Waterhouse Road attests to its vulnerability to extinction. It appears to have no close relative, showing only weak electrophoretic similarity to *E. fossor*, a species widely distributed in northern and western parts of Tasmania. Alternatively, there is the possibility that *E. spinicaudatus* and a species from South Gippsland (*E. phyllocercus*) belong to the same clade, since both have a terminal uropodal spine. If so the significance for conservation of both species increases, and given that *E. phyllocercus* is regarded as rare (Horwitz 1990b), the clade may be considered to be threatened. Therefore it should be incumbent upon governments in both Tasmania and Victoria to ensure that respective populations are not driven to premature extinction.

The above examples demonstrate the need to take into account the relictual status of species in question, as well as their phylogenetic status and the conservation status of other species in the same clade, before assessing regional conservation priorities.

Discussion

Within the northeast Tasmanian region, endemism in the genus Engaeus is relatively high: of the eight species found there, four are restricted to it and a fifth (*E. mairener*) is almost restricted to it. These data are supported by janirid isopods with two endemic electromorphs found without conspecific populations in southern Australia. The parapatric boundary between *E. leptorhynchus* and *E. tayatea* may represent a 'faunal break' but congruence data is required from other invertebrate groups to substantiate the claim. A 'hot spot' of diversity occurs in the Mt Horror area, demonstrated by the genus *Engaeus*: one species is locally restricted to just west of Mt Horror and another five species can be found within a 20 km radius of it. With another freshwater crayfish (*Astacopsis gouldi*) also occurring in the region, it may represent the most diverse local area for freshwater crayfish in Australia.

The western boundary of the Ben Lomond bioregion is supported by the distribution of *E. nulloporius*, which occurs immediately outside the region (fig. 1), and by the absence of *A. gouldi* from rivers and creeks of the Tamar drainage and between Port Sorell and Launceston. These data also support an East Tamar faunal break (Mesibov 1994). The southern boundary of the bioregion is supported by an absence of *Engaeus* from south of the Fingal Valley.

The malacostracan crustaceans examined here therefore support the concept of a bioregion for northeast Tasmania from a Tasmanian perspective, but can it be considered sufficiently distinct from the Furneaux Group and southern Victoria to warrant a separate bioregional status?

Northeast Tasmania - Southeast Victoria connection

Four species examined here have populations both inside and outside the northeast Tasmanian bioregion. In *Engaeus* one species has populations in northeast Tasmania and southeast Victoria, and one has populations distributed all around Bass Strait. In *Astacopsis*, one species is distributed along the north of the island of Tasmania, and the other has northeast, southeast and southwest Tasmanian populations according to current taxonomies. The data are therefore equivocal concerning the affinities of northeast Tasmania at this level. At the supraspecific level, it is clear that a significant proportion of the northeast Tasmanian malacostracan taxa examined can be hypothesized to have their closest relative(s) in southern Victoria (mainly South Gippsland) or on the Furneaux Group of islands, namely some janirid isopods, *A. franklinii*, *Engaeus orramakunna* and *E. leptorhynchus*, and *E. cunicularius*. This is the most significant trend for the distribution of related taxa in the groups analysed, other than patterns of endemism as described above.

On a regional scale, there appears to be an east-west split in the crayfish fauna in Tasmania at least, highlighted in the recent paper of Mesibov (1994) for *Astacopsis* and *Parastacoides*, and in this paper for *Engaeus*. It is apparent, however, that the east-west split also manifests itself in Victoria for freshwater crayfish groups, such that the northeast Tasmanian fauna shares close (closest?) affinities with southeast Victorian macrocrustacean fauna. It is possible, therefore, that Tyler's Line (Mesibov 1994) may be a southern extension of an east-west split in the far southern part of southeast mainland Australia, not just Tasmania. Other crustacean taxa support this view; for instance, crayfish species in the genus *Geocharax* are found only in northwest Tasmania, on King Island, and in southwest Victoria and southeast South Australia. Similarly the syncarid family Koonungidae, consisting of the genera *Micraspides* and *Koonunga*, has so far only been found in west Tasmania, southwest Victoria and southeast South Australia.

These suggestions strengthen the claim that the

systematics and biogeography of northern Tasmanian taxa cannot be understood without reference to southern Victorian forms and vice versa, from the infraspecific to supraspecific levels. Similarly, criteria used in assigning priorities for biodiversity conservation should include genetic distinctiveness, or representation in clades. In the case of northeast Tasmania, an examination of the adequacy or otherwise of reservation of taxa should include an assessment of related Victorian forms.

Acknowledgements

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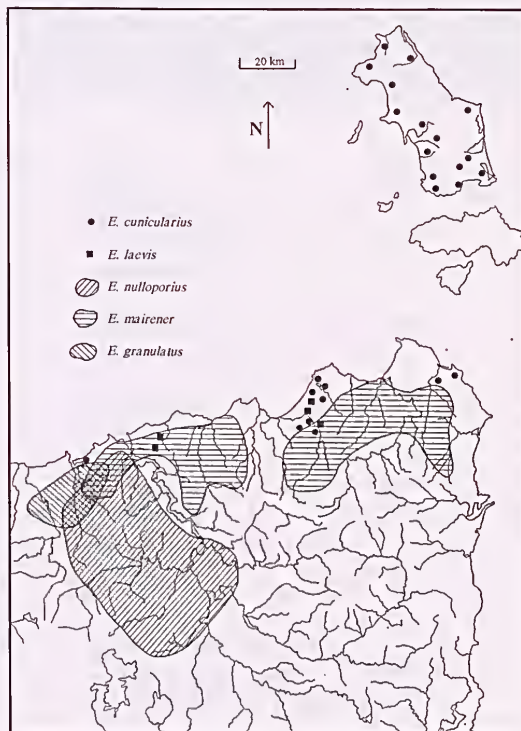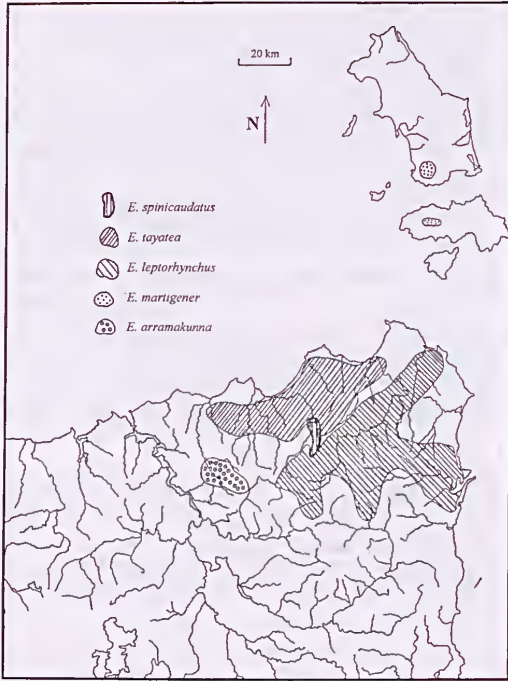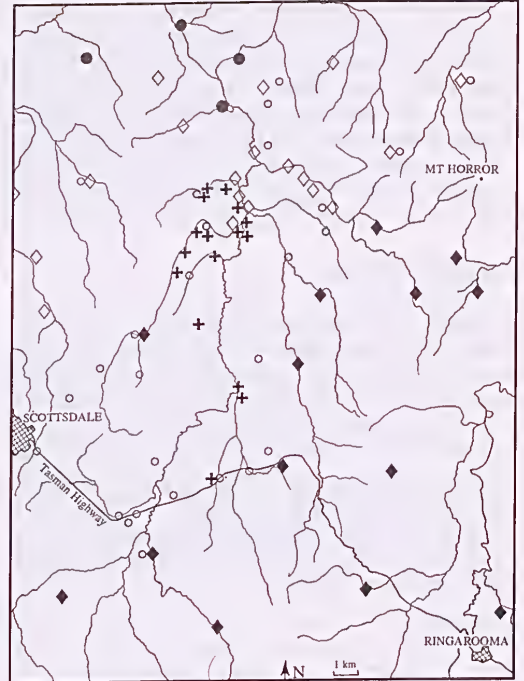

Fig. 1. Northeast Tasmania, showing known occurrences of *E. cunicularius* and *E. laevis* and the geographic extent of three closely related species.

Fig. 2. Northeast Tasmania, showing the geographic extent of five species in the genus *Engaeus*, with one of them (*E. martigener*) endemic to islands of the Furneaux Group. The non-overlap of *E. tayatea* and *E. leptorhynchus* (parapatric boundary) runs northeast-southwest and is particularly pronounced immediately east of the *E. spinicaudatus* occurrences.

Fig. 3. Localities of freshwater crayfish collected from an area west of Mt Horror, near Scottsdale in northeast Tasmania. The map shows only sites where crayfish were found, not sites where crayfish were not found. Species are *E. leptorhynchus* (closed diamonds), *E. tayatea* (open diamonds), *E. spinicaudatus* (black crosses), *E. cunicularius* (closed circles) and *E. mairener* (open circles).

Table 1. Data used to determine phylogenetic relationships for northeast Tasmanian species in the genus *Engaeus*. Data include morphological characters and phyletic interpretations of electrophoretic data as given in Horwitz et al. (1990).

Species Characters (with hypothesized closest relative)

E. cunicularius	*Fully developed exopodite of third maxilliped, presence of sternal pores* and nature of sternal keel and lateral processes, and setation on propodus of chelae; phyletic grouping from electrophoretic data (*E. quadrimanus*).
E. laevis	Strongly developed postorbital ridges, large uncalcified penes, nature of the lateral processes of the fourth pereopod (shared with *Gramastacus*).
E. maireuer E. nulloporius E. granulatus	Pattern of loss of sternal pores (Horwitz 1990a); phyletic grouping from electrophoretic data.
E. orramakunna E. leptorhyuchus E. martigener	Form of rostral carinae and tapering rostrum; loss of all sternal pores and reduced exopodite of third maxilliped (except *E. orramakunna*), and phyletic groupings from electrophoretic data (species group with the Victorian species *E. orientalis* and *E. australis* which show the same morphological traits).
E. tayatea	Unclear relationships.
E. spinicaudatus	Unclear relationships; terminal spines on uropods (*E. phyllocercus*); possible phyletic grouping from electrophoretic data (*E. fossor*).

Table 2. Distribution, closest relatives and conservation status of northeast Tasmanian species in the genus *Engaeus*. 'Endemic' refers to the distribution with respect to the Ben Lomond biogeographical region (*sensu* Thackway & Cresswell 1995). Conservation status according to Invertebrate Advisory Committee (1994) or Horwitz (1995). 'A.N.T.' = apparently not threatened.

Species	Distributional Status	Conservation Status	Closest Relative (with distribution)	Conservation Status of Clade
E. cunicularius	Vic., Tas. near Bass Strait	A.N.T.	*E. quadrimanus* (southeast Vic.)	A.N.T.
E. laevis	southeast Vic. northeast Tas.	A.N.T.	*Gramastacus* (west and north Vic.)	A.N.T.
E. maireuer	mainly northeast Tasmania	A.N.T.	*E. granulatus, E. nulloporius*	A.N.T.
E. nulloporius	central northern Tasmania	A.N.T.	*E. granulatus, E. maireuer*	A.N.T.
E. granulatus	central northern Tasmania	A.N.T.	*E. maireuer, E. nulloporius*	A.N.T.
E. orramakunna	endemic	Vulnerable	*E. leptorhyuchus* group	
E. leptorhyuchus	endemic	A.N.T.	*E. leptorhyuchus* group (northeast Tas., southeast Vic.)	A.N.T.
E. tayatea	endemic	A.N.T.	unknown	unknown
E. spinicaudatus	endemic	Vulnerable	unknown	unknown

The Influence of Gradients of Altitude and Rainfall on the Distribution of Native Earthworms in Northeast Tasmania

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Abstract

The topic of earthworms in northeast Tasmania is introduced through an examination firstly of the statewide distribution patterns of species occurring within the region, and secondly of the question of whether the Northeast could be considered to be a faunal province for the group. The paper will then examine the species composition and abundance of earthworms on an altitudinal sequence of soils derived from Siluro-Devonian sandstones (Mathinna Beds) in northeast Tasmania. Within the sequence of seven soils, profile development, vegetation structure, floristics, and earthworms all exhibit significant variation under the influence of a rainfall gradient of 900 to 1 400 mm that corresponds to elevations from 80 to 500 mm. Representatives of each of the main ecological groups of earthworms were present at the high-altitude rainforest site: litter dwellers, topsoil residents (dominated by *Megascolex montisarthuri*) and one subsoil species (*Pinguidrilus tasmanianus*). *M. montisarthuri* is abundant at the wetter sites, but its density declines with altitude and rainfall, until at the driest sites it was found only occasionally. *P. tasmanianus* was found only at the wetter sites above 250 m. The density and diversity of additional less abundant litter and topsoil species also declined with altitude. Finally, some comments are made on the influence of the earthworm fauna upon soil profile development and nutrient recycling across the soil sequence.

An Overview of the Insect Fauna of Northeast Tasmania

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Abstract

In spite of modest attention paid to the Northeast compared to other areas of Tasmania, a number of tentative generalisations can be drawn from our present understanding of the regional insect fauna. There is an underlying dominant spectrum of geographically widespread species, but the fauna is special by virtue of (a) various locally endemic taxa at the level of genus, species and subspecies; (b) a number of outliers of mainland Australian taxa which have their only Tasmanian populations confined to the region; and (c) the apparent absence of species expected to be present on ecological grounds. The Northeast also receives annual influxes of airborne species from the mainland, some of which may breed locally until eradicated by declining temperatures in autumn. The insect fauna is rich in soil-dwelling species which are favoured by the large extent of Quaternary sands in a warm and relatively moist coastal environment.

Where Does the Northeast Begin? - A Millipede's View

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Abstract

Polydesmidan millipedes are relatively large litter invertebrates which are ubiquitous in Tasmania, readily collected at any time of year and easily identified. Their usefulness as zoogeographical tools is enhanced by their modest species-level diversity (fewer than 100 Tasmanian species) and their often small ranges with well-defined range boundaries. Intensive millipede surveys in northeast Tasmania have revealed striking distributional congruences. Plomley's Island is an area of millipede endemism centred on the wetter, northern portion of the Northeast highlands. The East Tamar Break, running parallel to the Tamar estuary, is a narrow landscape zone containing range boundaries for a number of polydesmidan millipedes and other litter invertebrates. Several species endemic to northeast Tasmania extend to the East Tamar Break but no further west, and it is suggested that a Northeast zoogeographical region could be said to begin at the Break, 20 km east of Launceston.

Freshwater Molluscs of Northeast Tasmania

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Abstract

Northeast Tasmania has a freshwater molluscan fauna similar to that found in the rest of Tasmania, with native members of the families Sphaeriidae, Planorbidae, Ancylidae and Lymnaeidae being widespread. There are 12 locally endemic named species of freshwater molluscs, all but one members of the Hydrobiidae, and several additional unnamed locally endemic taxa including hydrobiids and glacidorbids are known. Of the named taxa, a freshwater mussel (Hyriidae) and three species of hydrobiids are endemic to the Tamar-Esk system. The known distributions of the locally endemic species lie almost entirely outside areas afforded any conservation status.

Introduction

Although much of Tasmania's freshwater biota remains poorly known, it is well established that there are many indigenous freshwater animals (e.g. Bayly & Williams 1965). Some of the more diverse animal groups are stoneflies (Plecoptera; Hynes 1989), caddis flies (Trichoptera; Neboiss 1977, 1981), yabbies (Decapoda, Parastacidae; Horwitz 1990), hydrobiid snails (Gastropoda; Ponder et al. 1993), phreatoicid isopods (Knott 1975), dragonflies (Houston & Watson 1988) and fishes (Fulton 1990). Interestingly, there has been a perception (e.g. Darlington 1965, Guiler 1965) that there is low endemicity in Tasmania's freshwater biota, perhaps because there are no endemic aquatic tetrapods or macrophytes.

The freshwater molluscs of Tasmania were reviewed by Smith and Kershaw (1981), who provided distribution maps of each species and a key to the families and species then recognised. Since that time Smith (1992) has produced a catalogue of the non-marine molluscs of Australia and updated much of the nomenclature. In the last decade there has also been extensive field work done throughout Tasmania by the author and his colleagues (fig. 1), which has substantially added to the available information. The present paper summarises this information for northeast Tasmania.

The freshwater molluscan fauna

The freshwater molluscs of Tasmania are contained in eight families, all of which occur in the Northeast of Tasmania; two of them are members of the Bivalvia (Hyriidae and Sphaeriidae), the remainder gastropods. Only one caenogastropod family, Hydrobiidae, is found in Tasmania freshwaters, and five pulmonate families (Glacidorbidae, Planorbidae, Ancylidae, Lymnaeidae and the introduced Physidae).

There are only two species of freshwater mussels (Hyriidae) in Tasmania. One of these, *Velesunio moretonicus* (Sowerby 1867), is an endemic taxon restricted to the South Esk River system. The other, *Hyridella narracanensis* (Cotton & Gabriel 1932), is also only found in the South Esk River system in Tasmania, but it also occurs in some coastal rivers in South Australia and Victoria. The biology and taxonomy of these species are rather poorly known (McMichael & Hiscock 1958) and modern techinques need to be applied to test their relationship with mainland congeners.

Smith and Kershaw (1981) recognised only two species of Sphaeriidae in Tasmania. In a subsequent taxonomic review of the group, Kuiper (1983) recognised five species of *Pisidium* and two of *Sphaerium* from Tasmania, including a new species (*Pisidium fultoni*) from Arthurs Lake and Lake Sorell. He recorded only three species from the Northeast, although he had rather limited collections at his disposal. More importantly, Kuiper's review was based only on shell characters and his taxonomic conclusions therefore require confirmation using additional character sets.

Although there are five families of freshwater pulmonate gastropods in Tasmania there are few species and these, as presently interpreted, are widely distributed. The Physidae, represented only by *Physa acuta* Draparnaud 1805 in southeast Australia, has been introduced, probably from Europe (Smith 1992). This species has recently been recorded by Kershaw (1991) from Tasmania and, although no details of its distribution were given by Kershaw, the author has found it at several northeast Tasmanian localities. It is very similar to the planorbid genus *Glyptophysa* in shell shape and the two taxa are often misidentified.

The planorbids are the most diverse basommatophoran pulmonate family in Australia, but appear to be rather poorly represented in Tasmania. The best known Tasmanian genus is the limpet-like *Ancylastrum*, with two species, *A. cumingianus* (Bourguignat 1853) and *A. irvinae* (Petterd 1888), both from the Central Plateau (Hubendick 1964, Walker 1988). These large and unusual species have been regarded as endangered for several years (Michaelis 1984).

The genus *Glyptophysa* (previously known as *Physastra*; Walker 1988) is common in many types of water bodies throughout much of Tasmania. Smith and Kershaw (1981) recognised two species, *P. gibbosa* (Gould 1846) and *Isidorella hainesii* (Tryon 1866). Smith (1992), however, listed two valid species from Tasmania, *G. huonensis* (Tenison-Woods 1876) and *G. pyramidata* (Sowerby 1873) with *I. hainesii* confined to the mainland, the genus *Isidorella* being absent from Tasmania (Walker 1988: p. 66). Specimens of *Glyptophysa* show considerable interpopulation variability in shell morphology, and to date all of the species-level taxonomy has been based on shell shape. While a number of morphs of this taxon have been examined anatomically to confirm their generic status (J. Walker, pers. comm.), no species-level revision of the group in Tasmania, or on the mainland, has ever been attempted. Thus the recognition of two species in Tasmania, and the validity of the names used for these taxa, is in urgent need of review.

Smith and Kershaw (1981) recognised three species of discoidal planorbids, all members of the genus *Gyraulus*: *G. scottianus* (Johnston 1879), *G. tasmanicus* (Tenison-Woods 1876) and *G. meridionalis* (Brazier 1875). All of these species occur in northeast Tasmania. Smith (1992) added the widespread species *Helicorbis australiensis* (Smith 1882) (see Brown 1981 for review) to the Tasmanian fauna, although no locality details were given, and transferred *G. scottianus* to the genus *Pygmanisus*. Two additional planorbids, the large European rams horn snail, *Planorbarius corneus,* and the North American *Helisoma* sp., have been recorded as introduced species (Kershaw 1991).

Only two species of freshwater limpets (family Ancylidae) are recognised; these occur throughout much of Australia (Hubendick 1967, Smith 1992), and both occur in northeast Tasmania (Smith & Kershaw 1981). However, the systematics of this group are greatly in need of revision and it is probable that the current highly conservative taxonomy will eventually be shown to be inadequate.

The worldwide members of the Lymnaeidae were reviewed by Hubendick (1951), and Boray and McMichael (1961) provided a detailed taxonomy of Australasian taxa. As a result of these studies there are only a few species now recognised in Australia and only one named native species in Tasmania, *Austropeplea tomentosa* (Pfeiffer 1855), a known intermediate host of liver fluke (*Fasciola hepatica* Linnaeus 1758) (Boray 1964). In addition, an undescribed genus and species is known from the Franklin River, southwest Tasmania (Ponder et al. 1994a). Smith (1992) also lists another Australian species, *A. lessoni* (Deshayes 1830), from Tasmania but that species is apparently only known from aquaria in Tasmania (Kershaw 1991). The introduced species *Pseudosuccinea columella* (Say 1817), *Lymnaea stagnalis* (Linnaeus 1758) and *L. peregra* (Müller 1774) are recorded from Tasmania (Kershaw 1991, Smith 1992)

and the former two species are known from the Northeast. *P. columella* is also an important intermediate host of liver fluke.

Unlike the other freshwater pulmonate families, the Glacidorbidae (Ponder 1986) has most of its known species in Tasmania where, in addition to the three named (Smith 1992), there are a number of undescribed species (Ponder, unpublished results). Smith and Kershaw (1981) do not record species of *Glacidorbis* from Northeast Tasmania but recent field work has shown that the genus is widespread in the area (fig. 2) and is represented by two or three undescribed species.

Of the seven 'prosobranch' families found in inland waters in Australia (Smith 1992), only the Assimineidae, Pomatiopsidae and Hydrobiidae are known from Tasmania. However, the Tasmanian assimineid species are only found in estuarine habitats (Kershaw 1983) and the single species of pomatiopsid, *Coxiella striata* (Reeve 1842), is found in saline coastal lagoons (Smith & Kershaw 1981). In contrast, most hydrobiids occur in freshwater, but the genera *Tatea,* with two species (Ponder et al. 1991), and *Ascorhis,* with one species (Ponder & Clark 1988), are found in estuarine and coastal brackish habitats in Tasmania and the rest of temperate Australia. Tasmania has been known for many years to have a more diverse fauna of hydrobiids than the mainland of Australia (Woods 1876; Johnston 1879; Petterd 1879, 1889; May 1921). However, it was not until the recent studies of the *Beddomeia* group (Ponder et al. 1993) that the full extent of the diversity of the fauna was realised. Sixty species-group taxa are now named from Tasmania, eight from the Northeast. A further three taxa border the area (fig. 3).

Hydrobiids can be very restricted in their distribution. While much more survey work needs to be carried out, it is nevertheless clear that many species occupy very small areas, such as a single catchment, or possibly even single streams or springs. Genetic studies at Wilsons Promontory in Victoria (Ponder et al. 1994b) have demonstrated that very little gene flow between hydrobiid populations occurs in streams in forested areas. Genetic differentiation can be considerable between populations isolated in different tributaries or even in different parts of the same tributary. The evidence suggests that hydrobiids are generally very poor dispersers and are consequently tied to a particular place for very long periods of time. However, there is one notable exception to this generalisation. *Potamopyrgus antipodarum* (Gray 1843) was introduced to Tasmania, Victoria and Britain from New Zealand in the middle of last century (Ponder 1988). Since then it has spread rapidly in Australia and Europe. It is now one of the most abundant animals in many Tasmanian streams, but even by the 1860s it was well established in parts of Tasmania and was named several times (Ponder 1988). It is widely spread in the Northeast (fig. 1). The dispersive success of this species is largely due to it being parthenogenetic and a brooder. In contrast,
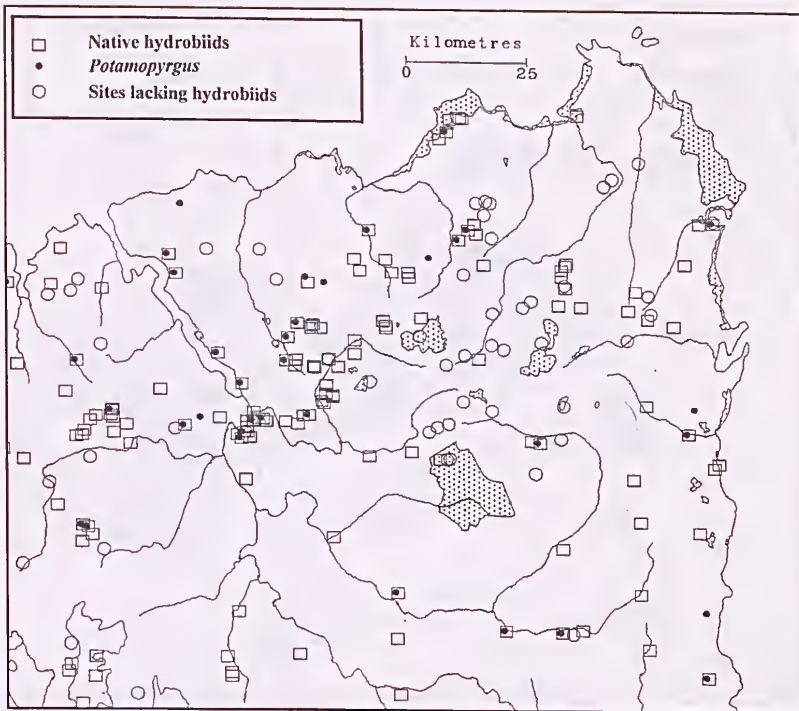
Fig. 1. Collecting sites in northeast Tasmania at which native hydrobiids were found (squares), those at which no hydrobiids were found (circles) and those at which *Potamopyrgus antipodarum* was found (dots). Protected areas are indicated by stipple.
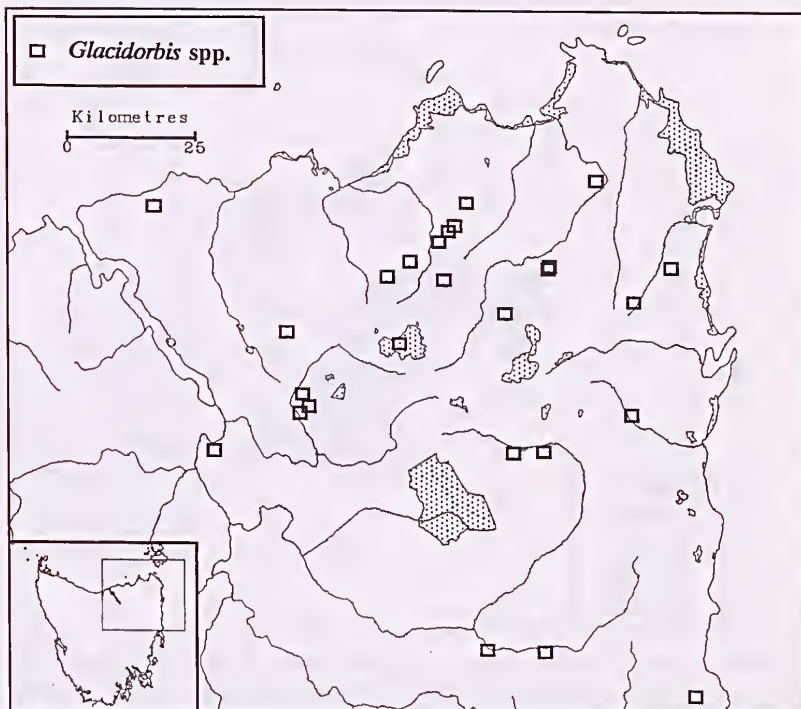

Fig. 2. Distribution of *Glacidorbis* species in northeast Tasmania. Protected areas are indicated by stipple.
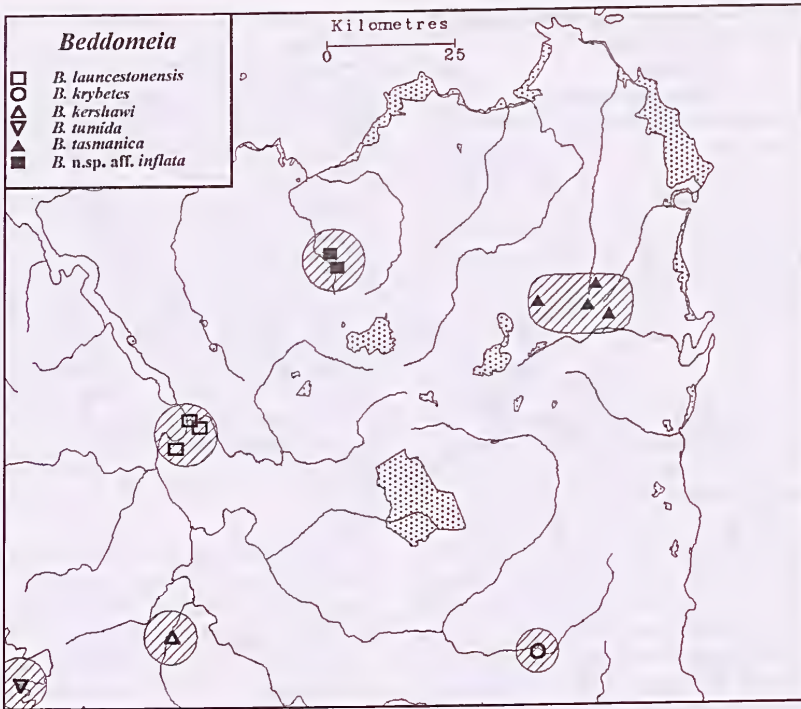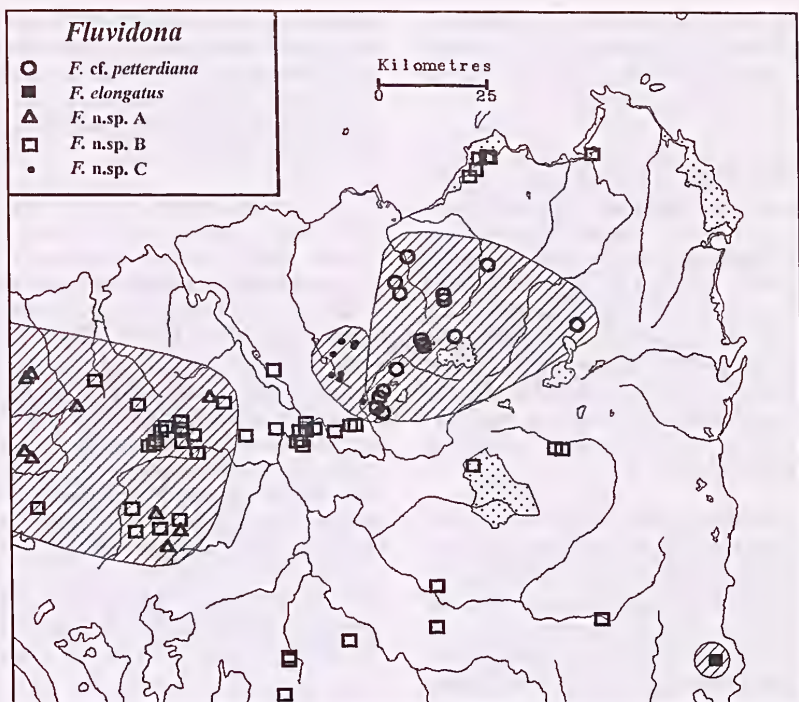
Fig. 3. Distribution of species of *Beddomeia* (see inset for details). Conservation reserves are indicated by stipple and the hatched areas summarise the distribution of each species.

Fig. 4. Distribution of species of *Beddomeia* (see inset for details). 'Unidentified' are populations similar to *B. minima* and related species that have not been definitely assigned to a species, or represent additional species-group taxa. Conservation reserves are indicated by stipple and the hatched areas summarize the distribution of each species. The dotted line encompasses the total known distribution of this species grouping.

Fig. 5. Distribution of species of *Fluvidona* (see inset for details). Conservation reserves are indicated by stipple and the hatched areas summarise the distribution of each species.
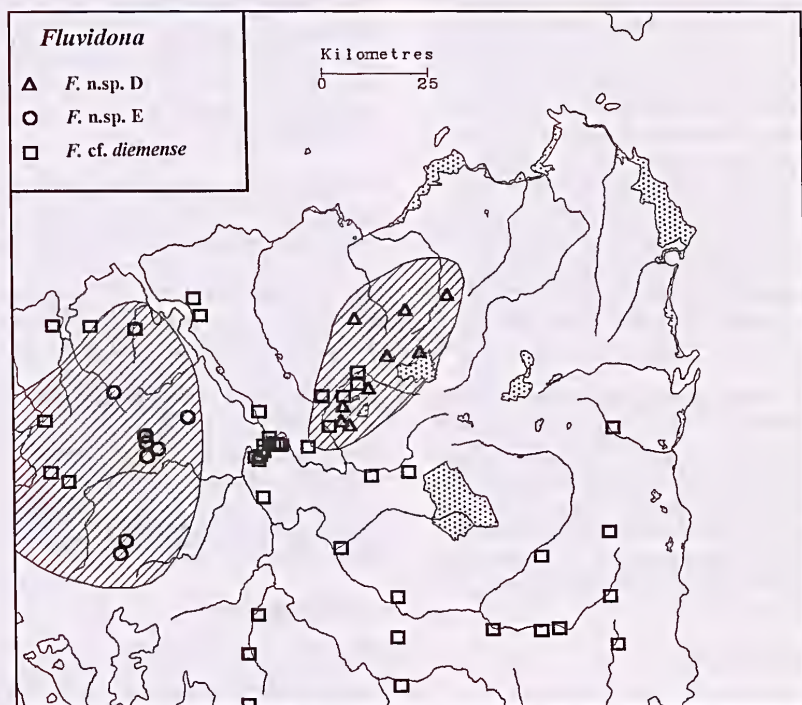

Fig. 6. Distribution of species of *Fluvidona* (see inset for details). Conservation reserves are indicated by stipple and the hatched areas summarise the distribution of each species.

native hydrobiids are dioecious and lay egg capsules, attached to the substrate, which usually contain a single egg. Unlike *P. antipodarum*, many native species also appear to have narrow habitat preferences.

There are two genera of hydrobiids found in northeast Tasmania. Species of *Beddomeia* are generally rather globose and have a simple operculum, whereas species of *Fluvidona* are more conical in shape and have a pegged operculum. Only *Beddomeia* has been revised (Ponder et al. 1993), although the species of *Fluvidona* are currently being reviewed and preliminary results are given here. The species distributions, as presently understood, of the hydrobiids of the Northeast and adjacent areas are shown in figures 3-6. These are based on a moderate sampling intensity (fig. 1) and further sampling will, no doubt, increase the number of taxa and extend the ranges of at least some of the known taxa.

There are a few additional species of *Beddomeia* that are known but not yet described. One of these includes a species very similar in shell characters to *B. inflata* Ponder et al. 1993 from the mid-north coast. When the *Beddomeia* review was undertaken this new species was known only from a few specimens in a small stream near Scottsdale but it has since been recollected at the same site and another site nearby (fig. 3). The globose shell of this species makes it one of the more distinctive of the *Beddomeia* species in the Northeast. Other species described by Ponder et al. (1993) (*B. fromensis, B. briansmithi*; see fig. 4) have rather similar shell morphology to *B. minima* Petterd 1889. *Beddomeia tasmanica* (T. Woods 1876) has a depressed spire and is restricted to a small area at Goulds Country. A somewhat similar species (*B. pallida* Ponder et al. 1993) and a smaller and even shorter-spired species (*B. ronaldi* Ponder et al. 1993) are found within the range of taxa similar to *B. minima*. *Beddomeia launcestonensis* (Johnston 1879) lives under large rocks in Cataract Gorge. Somewhat similar species described by Ponder et al. (1993) (*B. kershawi* and *B. krybetes*) are found in other parts of the Esk system just outside the Northeast. (fig. 3) Another similar species (*B. tumida* Petterd 1889) was described from Great Lake but may now be extinct.

Figures 5 and 6 show the currently known distributions of eight species of *Fluvidona* found in the Northeast, based on work in progress by the author and his co-workers. These taxa, as we currently recognise them, tend to have wider distributions than species of *Beddomeia*, this being particularly true for *Fluvidona* n.sp. B (fig. 5) and *F.* cf. *diemense* (fig. 6). Only two species of *Fluvidona* in this region, *F. elongatus* (May 1921) and *F.* n.sp. C, have restricted distributions (fig. 5).

Conservation considerations

The practical problems concerning the conservation of invertebrates have been outlined by Yen and Butcher (1992). The small size, lack of popular appeal and general obscurity of invertebrates do little to assist in getting them on the conservation agenda. However, if biotic diversity is to be maintained, it is essential that more attention be paid to the great majority of life that is not vertebrate or vascular plant (Wilson 1987, 1992; Wilson & Peter 1988; Ponder 1992; New 1995).

Of the freshwater molluscs in the Northeast, the several locally endemic species of hydrobiids all have rather small distributions, and most are known only from one or a few sites. Freshwater hydrobiids are typically associated with streams that have maintained permanent water over very long periods of time (Ponder 1994) and, for this reason, tend not to occur in areas subjected to Pleistocene glaciation. Many small streams on agricultural and urban land almost certainly contained hydrobiid faunas but are now so degraded that the original fauna has been lost. However, when degradation is moderate, particularly when riparian vegetation is maintained, hydrobiids have persisted, although they remain extremely vulnerable to a wide range of degrading influences. The impact of trout on hydrobiid populations has not been assessed, although it is well documented that trout eat a large range of aquatic invertebrates, including molluscs (Evans 1942, Wilson 1966, Knott 1975).

Figures 1-6 show the areas currently given formal status as conservation reserves. As can be seen, there is very little overlap with the distributions of the locally endemic hydrobiids, although this may be partly because there has been relatively little collecting effort in protected areas. However, the distribution patterns strongly suggest that the currently protected areas, which are mainly in areas of high elevation, will not contain most of the known narrow-range endemic species, which are mainly in lowland streams.

The high diversity of hydrobiids in Tasmania may be an indication that other poorly-dispersing aquatic invertebrates will prove to be much more speciose than currently realised. Certainly the freshwater burrowing crayfish fauna (Horwitz 1990) was found to be much more diverse than previously realised once it was examined carefully, and the same will probably be true for other crustaceans (e.g. many isopods and amphipods) as well as groups such as triclad flatworms. Many taxa within these groups, like many hydrobiids, are not resistant to desiccation and are presumably dependent on freshwater streams that maintain permanent flow over long periods of time. It is thus essential that we recognise the importance of such habitats in the conservation of locally endemic freshwater faunas.

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The Reptiles of Northeast Tasmania, with New Records and a Key to Species of Grass Skinks, Genus *Pseudemoia*

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Abstract

Seventeen of the 20 species of terrestrial reptiles native to Tasmania occur in the Northeast. Most of these species exhibit viviparity and heliothermy, which are considered to be necessary adaptations to life in a cool moist climate. The glossy grass skink, *Pseudemoia rawlinsoni*, is reported for the first time from the Tasmanian mainland and the tussock skink, *P. pagenstecheri*, for the first time from a nature reserve. Notes on specimens, habitats and new locations for these rarely collected species are reported. A key to Tasmanian species of *Pseudemoia* is provided.

Introduction

Tasmania contains a small and intriguing part of a large and diverse Australian reptile fauna. Sixteen scincid lizards, an agamid and three elapid snakes make up all the native terrestrial species known from the State (Rounsevell & Swain 1993). Tasmania lacks any gekkonid, pygopodid or varanid lizards, which occur in southern Victoria on the adjacent Australian mainland. Rawlinson (1974) first attempted an atlas of the Tasmanian reptile fauna. Since then taxonomic change, descriptions of new species, ecological studies and field surveys have added much to our understanding of the reptiles of the region.

Northeast Tasmania is at the southern end of the shallowest and most enduring former land connection with the Australian mainland. Subject to past sea-level and climatic changes, this was the most recent and most important bridge for faunal exchanges with mainland Australia. Despite the absence of some distinctive Australian taxa such as geckoes and goannas (except as accidental introductions), the variety of reptiles and their habitats in the Northeast shares more similarities with the adjacent mainland than does any other part of the State.

Basic ecological knowledge of many Tasmanian species is incomplete or missing. The Northeast region is very accessible but ecological knowledge of its reptile fauna is patchy. This paper summarises what is known of the reptile fauna of the region and reports on new records of the grass skinks of the genus *Pseudemoia*, two species of which are uncommon and poorly known in Tasmania. A key to their identification is provided.

Methods and materials

The morphological information was obtained by examining specimens collected in the field and held in museums in Tasmania, South Australia and Victoria.

Definitions and methods of making scale counts and taking measurements were those used by Hutchinson and Donellan (1992). Museum abbreviations used are NMV, Museum of Victoria, Melbourne; QVML, Queen Victoria Museum, Launceston; SAMA, South Australian Museum, Adelaide; and TMAG, Tasmanian Museum and Art Gallery, Hobart. In morphological descriptions, SVL = snout-vent length. The Tasmanian Wildlife Atlas is a database of biological records maintained by the Tasmanian Parks and Wildlife Service. Specific nomenclature used here follows Cogger (1992) unless stated otherwise.

Reptiles of northeast Tasmania

The number of published reptile surveys of the Northeast is small. Green (1979) reported seven species from coastal heath at Binalong Bay and Taylor et al. (1993) reported 10 species from forest at Old Chum Dam (near Herrick) over 13 months of monthly surveys. Unpublished surveys have been conducted by the authors at Waterhouse (RB), Cape Portland and Mt William National Park (DR) or by others known to us (e.g. at Ben Lomond; T. Schwaner, pers. comm.). Some others, including R.H. Green, A.E. Greer and P.A. Rawlinson, have collected widely in the region.

Currently 17 of the 20 species of native terrestrial reptiles in Tasmania (Rounsevell & Swain 1993) are known from the Northeast and adjacent islands (table 1). The three remaining species, *Niveoscincus palfreymani*, *N. microlepidotus* and *N. orocryptus*, are restricted to island and subalpine habitats in the south and the western highlands (Rounsevell et al. 1985; Hutchinson et al. 1988, 1989). Within the region there are four Tasmanian endemic species: *Niveoscincus greeni*, *N. pretiosus* and *N. ocellatus*, which occupy, respectively, subalpine, semi-arboreal and rocky habitats (Hutchinson & Schwaner 1991), and *Cyclodomorphus casuarinae* which lives on the ground in dense vegetation (Shea 1995). Only one of

Table 1. Reptiles of northeast Tasmania. (Tasmanian endemics indicated by *.)

Species	Present on eastern Bass Strait islands	Abundance on Tasmanian mainland
AGAMIDAE		
Mountain Dragon		
Tympanocryptis diemensis (Gray 1841)	+	common
SCINCIDAE		
Three lined Skink		
Bassiana duperreyi (Gray 1838)	+	common
She-oak Skink*		
Cyclodomorphus casuarinae (Dumeril and Bibron 1839)	-	widespread, common
White's Skink		
Egernia whitii (Lacepedes 1804)	+	common
Delicate Skink		
Lampropholis delicata (De Vis 1888)	-	common
Bougainville's Skink		
Lerista bougainvillii (Gray 1839)	+	restricted distribution
Northern Snow Skink*		
Niveoscincus greeni (Rawlinson 1975)	-	common, alpine habitat
Metallic Skink		
Niveoscincus metallicus (O'Shaughnessy 1874)	+	widespread, common
Spotted Skink*		
Niveoscincus ocellatus (Gray 1845)	+	common
Tasmanian Tree Skink*		
Niveoscincus pretiosus (O'Shaughnessy 1874)	-	common
Southern Grass Skink		
Pseudemoia entrecasteauxii (Dumeril and Bibron 1839)	+	common
Glossy Grass Skink		
Pseudemoia rawlinsoni (Hutchinson and Donellan 1988)	+	known only from 4 sites
Tussock Skink		
Pseudemoia pagenstecheri (Hutchinson and Donellan 1991)	+	restricted distribution
Blotched Blue-tongue Lizard		
Tiliqua nigrolutea (Quoy and Gaimard 1824)	+	widespread, common
ELAPIDAE		
Lowland Copperhead		
Austrelaps superbus (Gunther 1858)	+	north and east, common
White-lipped Snake		
Drysdalia coronoides (Gunther 1858)	+	widespread, common
Black Tiger Snake		
Notechis ater (Krefft 1866)	+	widespread, common

these species, *N. ocellatus*, is currently known from islands in the Furneaux Group (Hutchinson et al. 1989, Green & Rainbird 1993). The remaining 13 species found in the Northeast (table 1) also occur on the adjacent Australian mainland. Green and Rainbird (1993) listed publications containing information on reptile faunas of islands in the Northeast and included lists of reptiles collected for the Queen Victoria Museum during recent surveys (notably by N.P. Brothers). Thirty-nine islands in the Furneaux Group and 10 northeast coastal islands were included. Thirteen species are recorded from these islands (table 1). The record of *N. pretiosus* from Flinders Island, reported by Rawlinson (1967) and subsequently cited by

Green and Rainbird (1993), was regarded as questionable by Hutchinson et al. (1989). Five northeast Tasmanian species are not recorded from the adjacent offshore islands. In the case of *N. greeni*, suitable habitat is absent, but the reasons for the other absences (of *Cyclodomorphus casuarinae*, *Lampropholis delicata*, *Niveoscincus pretiosus* and *Pseudemoia pagenstecheri*) are not obvious. The absence of *P. pagenstecheri* from superficially suitable grassy habitat on the larger Furneaux Group islands is discussed below.

The Tasmanian reptile fauna shows a pattern of adaptive responses to the relatively cool, humid climate. All but

one species are heliothermic, actively basking to elevate the body temperature above the generally low air temperature. Only *L. bougainvillii* is a thigmotherm and is consequently limited to the warm, open habitats of the eastern Bass Strait islands, barely colonising the Tasmanian mainland on its two northeasternmost promontories (Cape Portland and Waterhouse Point).

Like New Zealand (Towns 1985), Tasmania has a reptile fauna dominated by viviparous species. The three egg-layers, the agamid *Tympanocryptis diemensis* and the skinks *Bassiana duperreyi* and *Lampropholis delicata*, depend upon a warm microclimate for successful incubation. Consequently they are confined to the warmest parts of the State, including the Northeast. *Lerista bougainvillii* is remarkable in that it includes both egg-laying and live-bearing populations. On the Australian mainland it lays eggs but on the Tasmanian mainland and on Kangaroo Island (South Australia) females bear live young (Qualls et al. 1995). These results come from one of a number of recent studies of reptiles in cool climates that are examining the development of viviparity in reptiles (Stewart & Thompson 1993; Thompson & Stewart 1994; S. Hudson, pers. comm.).

The three elapid snakes (table 1) are widespread in the Northeast (Rawlinson 1967, 1974; Fearn 1993, 1994). The response of *Notechis ater*, the tiger snake, to prey availability on islands in the Furneaux Group (Schwaner 1985, Schwaner & Sarre 1988) is a well-known example of adaptive variation in reptiles. Tasmanian populations of tiger snakes vary widely (Fearn 1993) and the subspecies of *N. ater* recognised by earlier workers (eg. Worrell 1963) are no longer regarded as valid (Rawlinson 1991). Work in progress by Schwaner even queries whether *N. ater* is specifically distinct from the mainland species *N. scutatus* (T. Schwaner, pers. comm.).

The grass skinks, genus *Pseudemoia*, in Tasmania

Grass skinks in the genus *Pseudemoia* are small lizards (SVL approx. 50 mm, length 120 mm including tail) that live on the ground in dense vegetation. Hutchinson and Donnellan (1988, 1992) reported *P. entrecasteauxii*, *P. pagenstecheri* and *P. rawlinsoni* from Tasmania and summarised data on their variation and ecology. The three species are superficially alike in appearance (Donnellan et al. 1993), but occupy different habitats. All are viviparous, possessing an advanced form of placentation which can supply nutrients directly to the developing embryo from the maternal blood stream, augmenting or even largely supplanting the yolk sac nutrition which is the primary source of embryonic nutrients in other live-bearing reptiles (Stewart & Thompson 1993, Thompson & Stewart 1994). Mating occurs in autumn and females ovulate in spring. Young are born from late December to February.

The habitat of *Pseudemoia entrecasteauxii* is grassy woodlands, forests and heathlands from the Blue

Mountains of New South Wales, through the southeast mainland, the Bass Strait islands and Tasmania, to the islands of Spencer Gulf, South Australia (Hutchinson & Donnellan 1992). *Pseudemoia pagenstecheri* is cryptic, living in tussock grassland habitats generally lacking trees in four disjunct areas on the Australian mainland from the New England Tableland through to the Grampians and, possibly, southeast South Australia (Hutchinson & Donnellan 1992). In Tasmania the species was previously only known from the Midlands (Hutchinson & Donnellan 1992; see below). *Pseudemoia rawlinsoni* occurs in moist habitats: at low altitudes in saltmarshes, wet heaths, swamps and margins of lakes, rivers and creeks; and at high altitudes in swamps, fens and sphagnum bogs (Hutchinson & Donnellan 1988). It has a disjunct distribution from southeast South Australia, southwest and south-central Victoria, alpine areas of northeast Victoria through the Snowy Mountains of New South Wales to the Brindabella Ranges on the Australian Capital Territory - New South Wales border (Hutchinson & Donnellan 1988). As an indication of the relative abundance of the three species, it may be noted that Hutchinson and Donnellan examined 83 Tasmanian specimens of *P. entrecasteauxii* from 35 localities, 13 specimens of *P. pagenstecheri* from five localities and a single specimen of *P. rawlinsoni* from Cape Barren Island in the Furneaux Group (Museum of Victoria specimen D12349).

Specimens of *Pseudemoia* can be difficult to locate in the field and difficult to identify once found. Tasmanian specimens of the three species are discussed below to assist field workers in locating and distinguishing them from one another and to provide further background on their habits and habitats in Tasmania.

Pseudemoia rawlinsoni

Four specimens are known from Tasmania (fig. 1), the first three all initially registered as *Leiolopisma entrecasteauxii*:

NVM D12349, Cape Barren Island (40°22'S, 148°02'E), male, J. Whinray, 1 May 1967. Habitat details not recorded.

QVML 1978/3/130, Round Hill (41°14'S, 148°17'E), female, R.H. Green, 4 October 1978. Collected in dry heathland on an ecotone between dry sclerophyll forest and wet heathland subject to frequent flooding (Green 1979).

QVML 1988/3/14, Launceston (41°26'S, 147°08'E), female, E.R. Green, 23 December 1988. Collected from rushy grass along the levee bank of the North Esk River between Tamar Street bridge and Killafaddy abattoir.

SAMA R44322, North Esk River, 1.5 km SW of Blacksnake Marsh (41°28'55"S, 147°30'07"E), female, R. Brereton, 7 August 1994. Found with several specimens of *Niveoscincus metallicus* inside a rotting fencepost laying in rank introduced grasses alongside a road. The adjacent low-lying paddock is subject to

Fig. 1. Distribution of *Pseudemoia rawlinsoni* in Tasmania (source: Tasmanian Wildlife Atlas)

flooding.

Scalation: Frontoparietal shields paired. Interparietal almost as large as a frontoparietal. Midbody scales in 25-28 rows, the dorsals, including paravertebral scales, with three distinct, rounded keels. Supraciliaries six (asymmetrically 7/6 in R44322). Upper labials seven. Prefrontals widely separated. Subdigital lamellae 17-21, smooth, rounded, basal two or three divided.

Size: SVL 49 mm (male), 54-63 mm (females). Tail regenerated in all four specimens. Hind limb length 35% (male), 27-33% (females) of SVL. Diameter of palpebral disc 52-57% of eye length.

Colour (R44322), freshly preserved specimen: dorsal surface of back, head, limbs and tail dark olive-brown. Broad black vertebral stripe from nape to base of tail. Additional black edging to scales produces weak narrow paravertebral lines running between the vertebral and dorsolateral lines. Narrow grey-white dorsolateral stripe runs along scale row 3, edged above and below by black. Narrow white midlateral stripe runs along scale row 6, running forward over the ear and finishing below the eye. This line also edged above and below in black from forelimb to hindlimb. Upper lateral zone between the two light stripes chocolate brown subdivided by a weak darker stripe. Underside pale buff, becoming dull white on the throat and chin. Plantar scales and subdigital lamellae dark brown to black. Dorsal scales highly glossy.

The two QVML specimens differ in having the black paravertebral stripes well developed, while these lines are absent from the Cape Barren Island specimen. In QVML

1978/3/130, which has the smallest midbody scale count (25), the midlateral white stripe runs along the junction of scale rows 5 and 6. The underside of the three longer-preserved specimens is dull grey-white.

The adult females represent different stages of the breeding cycle. The specimen collected in autumn (SAMA R44322) lacks any development of yolked ovarian follicles. V-shaped bite scars (mating marks) are present on the back and belly at the level of the forelimbs. The early spring specimen (QVML 1978/3/130) has seven oviducal eggs with no obvious sign of embryonic development. The early summer specimen (QVML 1988/3/14) has nine nearly full-term young which are scaled and pigmented. The male has regressing testes. For both sexes, the pattern of the reproductive cycle corresponds to that seen in mainland Australian specimens.

The specimens fall well within the variation reported for this species by Hutchinson and Donnellan (1988). Only the largest female (QVML 1988/3/14) is exceptional. It is the largest specimen of the species yet recorded (previous maximum SVL 61 mm for NMV D37325, Whittlesea, Victoria), has the largest litter size (nine, previous maximum litter size eight, also for D37325) and relatively the shortest limbs (shortest hind limb length reported by Hutchinson and Donnellan was 30% of SVL). All of these features may be correlated and simply a function of size; no detailed allometric studies of *Pseudemoia* have been done as yet.

Habitat for this species in Tasmania is low dense vegetation in moist situations along the margins of swamps and watercourses. The waterlogged habitat where R44322 was collected is typical of the rural habitats occupied in Victoria. *Pseudemoia rawlinsoni* is probably more widespread in Tasmania than is currently known and could occur throughout the north and east including other islands of the Furneaux Group. Experience in Victoria indicates that the species will be difficult to locate, as indicated by the small number of specimens accumulated in mainland Australian museums (Hutchinson & Donnellan 1988) and in Tasmania to date.

Pseudemoia pagenstecheri

Hutchinson and Donnellan (1992) described Tasmanian populations of this species using eighteen museum specimens collected in Tasmania from five localities from the southern to northern Midlands: Jericho, 9.6 km N of Jericho, 22.3 km N of Rhyndaston, 6 km N of Lower Marshes, 5 km E of Evandale. Other specimens have since been collected from Township Lagoon Nature Reserve, Tunbridge, by DR (SAMA R45267-71); Smiths Lagoon, Cleveland, by P. Brown and J. Wapstra (TMAG C1030-31); and Queens Domain, Hobart, by RB (fig. 2).

Scalation features and dimensions of a sample of 18 Tasmanian *P. pagenstecheri* were provided by Hutchinson
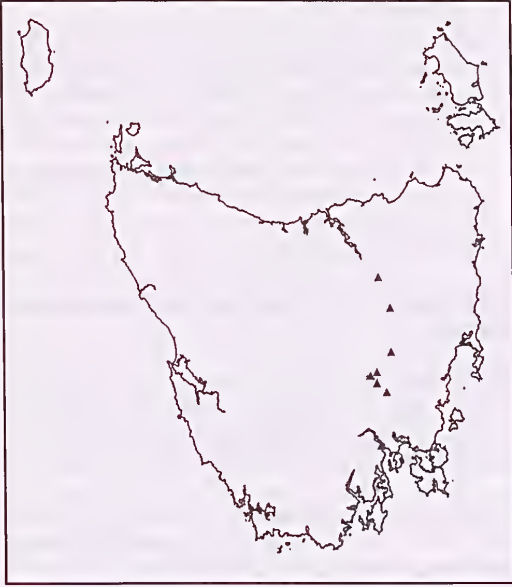
Fig. 2. Distribution of *Pseudemoia pagenstecheri* in Tasmania (source: Tasmanian Wildlife Atlas)

and Donnellan (1992), and the newer specimens fall within the range of variation reported by those authors.

Colour: dorsal surface of back, head, limbs and tail light greyish to dark olive-brown. Broad black vertebral stripe from nape to base of tail. Additional black edging to scales usually produces narrow paravertebral lines running between the vertebral and dorsolateral lines. Most specimens also have white flecks on some dorsal scales, in some cases arranged longitudinally, resulting in light margins to the black dorsal lines. Narrow buff dorsolateral stripe runs along scale row 4, or sometimes row 4 plus the lateral edge of row 3. This stripe is edged above and below by black. A straight-edged light grey (females) or red (males) midlateral stripe runs along one or more of scale rows 6 to 8, fading anterior to the forelimb but reappearing as a pale crescent under the eye. The lower lateral line has no dark stripe along its ventral margin. Upper lateral zone between the two light stripes with numerous dark-edged scales. Underside pale grey to pale yellowish, sometimes weakly flushed with pink or coppery colouring posteriorly, becoming white on the throat and chin. Plantar scales pale brown, subdigital lamellae dark brown to black. Dorsal scales with a matt or slightly glossy surface.

As with the previous species, the biology and appearance of *P. pagenstecheri* in Tasmania are not detectably different from those of conspecific populations in southern Victoria. The morphological variation and genetic variation analysed by Hutchinson and Donnellan (1992) suggest that the two populations have not diverged, presumably because they were continuous across the Bass Strait land bridge during the recent glacial maximum (10-20 000 years ago). Given this, it may seem

surprising that this species is not known to occur on any of the Bass Strait islands. We suggest that it does not occur in the Furneaux Group because suitable habitat was absent prior to European settlement (Harris & Davis 1995, Harris & Reimer 1994). Tussock grassland now present on these islands has appeared after recent contraction, or elimination in some cases, of woodland or forest plant species by fire and clearing (Edgecombe 1986).

The *P. pagenstecheri* population at Township Lagoon, Tunbridge, is the first known from a nature reserve. Now treeless, only the understorey of this relictual patch of eucalypt woodland habitat (community Eve of Kirkpatrick et al. 1988) remains and largely consists of a profusion of native grasses, including species of *Danthonia*, *Themeda*, *Poa*, *Agropyron* and *Microlaena*. The Queens Domain municipal reserve, the southernmost *P. pagenstecheri* locality, supports two grassy woodland communities (Evam and Evpv of Kirkpatrick et al. 1988) with a similar range of grass genera. At the Domain, *Themeda australis* dominates during warm months and *Poa rodwayi* during cool months. At Smiths Lagoon specimens were found under a log amongst grasses in the dry bed of an ephemeral wetland which is surrounded by a margin of lightly grazed *Poa-* and *Danthonia*-dominated native grassland on private property.

Throughout its range, *P. pagenstecheri* is confined to treeless tussock grassland and grassy open woodland. Only small remnants of such habitats exist today in Tasmania, mainly along roadsides and on unploughed land in the Midlands region between Hobart and Launceston (Kirkpatrick et al. 1988). Many native grassland communities in Tasmania have been destroyed by agriculture, but remnants of such habitats are probably more numerous than is currently documented, implying that *P. pagenstecheri* is also probably more widespread than the small number of known localities would suggest.

Pseudemoia entrecasteauxii

This species is much more widespread than the other two Tasmanian *Pseudemoia*, being found throughout Tasmania from sea level to subalpine elevations and on the larger Bass Strait islands (fig. 3). The species occurs in a variety of habitats, but is usually associated with woody vegetation, such as low to tall open forest, woodland, heathland and alpine herbfields (Hutchinson & Donnellan 1992). It is the only member of the genus present in the buttongrass moorlands in the west of the State. It is also more readily collected than either of the other species because its behaviour is less cryptic. It uses fallen logs and large rocks for basking and climbs more readily than the other species (Hutchinson & Donnellan 1992). Its geographic range includes those of the other two species; on the mainland it occurs syntopically with both *P. pagenstecheri* and *P. rawlinsoni*. In Tasmania, *P. entrecasteauxii* and *P. pagenstecheri* are found together at Evandale, Lower Marshes and the Domain, and other
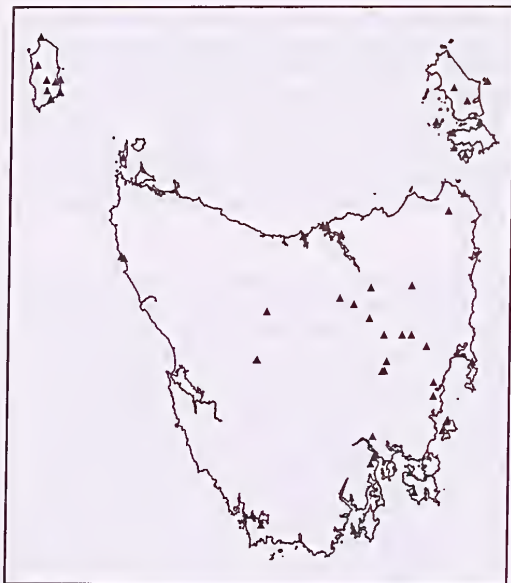
Fig. 3. Distribution of *Pseudemoia entrecasteauxii* in Tasmania (source: Tasmanian Wildlife Atlas)

instances of syntopy are likely to be revealed with further fieldwork.

Compared with the relatively consistent colour patterns of the other species of *Pseudemoia, P. entrecasteauxii* displays an extreme degree of colour pattern variation. This variation is made slightly less confusing by the presence of some geographic regularity in the distribution of colour pattern types, as follows:

• *Open forest pattern.* In the open forests of east and north Tasmania, *P. entrecasteauxii* is generally weakly patterned, with ragged light dorsolateral and midlateral lines, the latter sometimes reduced to a mere zone of pale flecks. The dorsal colouring is markedly metallic and the only dorsal stripe is a sometimes ragged black vertebral line.

• *Southwest and subalpine sedgeland pattern.* In buttongrass habitats *P. entrecasteauxii* specimens are usually heavily striped, with five black dorsal stripes and straight-edged light dorsolateral and midlateral lines. The midlateral line is edged below by a black line. Light dorsal or lateral flecks are absent.

• *Eastern Bass Strait pattern.* Specimens from the Furneaux and Kent Groups are often very similar to *P. pagenstecheri*, and inhabit similar open tussock grass-dominated habitats. The dorsum is often pale grey-brown without metallic lustre and pale dorsal speckling is commonly present. Unlike *P. pagenstecheri*, Furneaux Group *P. entrecasteauxii* usually have a black lower edge to the midlateral light stripe and bright red ventral colouring in breeding males; females also may have bright red bellies, at least while they are pregnant (Hutchinson

& Donnellan 1992).

• *King Island pattern.* King Island *P. entrecasteauxii*, like those from Flinders Island, often lack metallic tones and are heavily striped. They generally lack light dorsal flecks. This population includes particularly large individuals which are known to be genetically distinctive, indicating a greater degree of isolation (Hutchinson & Donnellan 1992) from both the Australian mainland and eastern Bass Strait-Tasmanian populations.

Key to the species of Grass Skinks (*Pseudemoia*) in Tasmania

In Tasmania members of the genus *Pseudemoia* are distinguished by their combination of divided frontoparietals (fig. 4), a large clear window in the lower eyelid and normally developed limbs.

1a) Pale dorsolateral stripe, if present, on scale row 4 (or both 3 and 4); dorsal scales matt or metallic-iridescent and either smooth or faintly triple keeled, with curved posterior margins in plan view; usually 28 or more midbody scale rows and five supraciliaries.   2

1b) Pale dorsolateral stripe always present and on scale row 3; dorsal scales highly glossy and strongly triple keeled, with straight posterior margins in plan view; usually 28 or fewer midbody scale rows and six supraciliaries.   *P. rawlinsoni*

2a) Dorsal surface pale olive, grey brown or dark brown, without metallic lustre; pale lateral stripes clear and straight-edged, without darker or lighter lateral speckling; pale midlateral stripe lacking distinct black lower edge; red colouring in breeding males limited to the midlateral stripe.   *P. pagenstecheri*

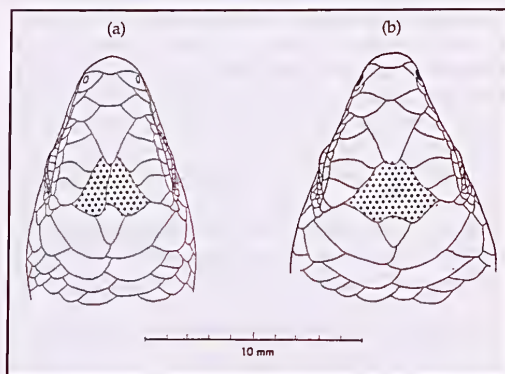2b) Very variable; dorsal colouring often with a metallic

Fig. 4. Dorsal view of the head of (a) *Pseudemoia rawlinsonii* and (b) *Niveoscincus microlepidotus* showing the frontoparietal shields (shaded), paired in *Pseudemoia* and fused in *Niveoscincus*. After Hutchinson and Donnellan (1988) and Hutchinson et al. (1989).

lustre and lateral striped pattern often broken by darker and lighter speckling; strongly striped specimens have a distinct black lower margin on the pale midlateral stripe; red colouring in breeding males includes both the midlateral stripe and the belly. *P. entrecasteauxii*

Acknowledgements

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Anoglypta Country: The Land Molluscs of Northeast Tasmania

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Abstract

The native land mollusc fauna of Tasmania (including the Bass Strait islands) consists of about 50 species in 11 families. While none of the families is endemic to the State, several genera are found nowhere else and over 75% of the species are Tasmanian endemics. Of this fauna, about 28 species in seven families are recorded from east of the Tamar and north of the Fingal Valley in northeast Tasmania. However only one species, the caryodid *Anoglypta launcestonensis* (Reeve, 1853), is confined to the Northeast. It is only found in the wet forest habitats of the more elevated areas and has a total distribution of approximately 2 500 sq km with the actual distributional area being much less. Several areas are known where good populations are recorded with one or two of these being in forest reserves. The conservation status of the species is discussed and the evidence considered from this and other mollusc species present for the designation of the Northeast as a faunal sub-region of the State.

Introduction

The land mollusc fauna of Tasmania is one of the most studied molluscan faunas in Australia. Several papers were written describing the fauna prior to the work of Cox (1864, 1868) who was the first to comprehensively treat the land snail fauna of Australia, including many Tasmanian species. Legrand (1871) then published the first monographic treatment of the Tasmanian fauna in a privately published book which started the great tradition of the documenting of the State's land molluscs by non-professional enthusiasts who have made a major contribution to our knowledge of the fauna. Petterd (1879) followed this with a further privately published monograph in which he significantly increased our knowledge of the relationships between species and the distribution and ecology of the species. This list was further revised by Petterd and Hedley (1909) and included in a comprehensive survey of the entire molluscan fauna of the State by May (1923). Iredale (1937a, 1937b, 1938) described and consolidated this knowledge as part of his basic list of the Australian fauna and Kershaw (1955, 1956a, 1956b) further increased this knowledge base. The detailed distribution of all the terrestrial species then known from the State was published for the first time by Smith and Kershaw (1981), and Smith (1992) included ecological and distributional descriptors for all the Tasmanian species in a detailed work on the entire non-marine mollusc fauna of Australia.

Mesibov (1994) discussed the significance of faunal breaks in Tasmania for invertebrate conservation. He showed that several faunal sub-regions are clearly seen within the State and demonstrated the existence of an area of faunal discontinuity in the Northeast which he called Plomley's Island. A number of invertebrate taxa were listed as being confined to this area, including the large land snail, *Anoglypta launcestonensis*.

Land mollusc fauna of northeast Tasmania

The State can be divided for biogeographic purposes into five sub-regions or zones (fig. 1). The line delineating Zone 2 (southern and western half of the State) corresponds roughly to Tyler's Line (Mesibov 1994); Zone 5 is bounded by lines down the Tamar and Fingal Valleys; Zone 3 is the drier eastern region; Zone 4 is the central north and Zone 1 the Bass Strait Islands. Sufficient is now known of the native land mollusc fauna of the State to allow a distributional listing for each species at least within these five zones.
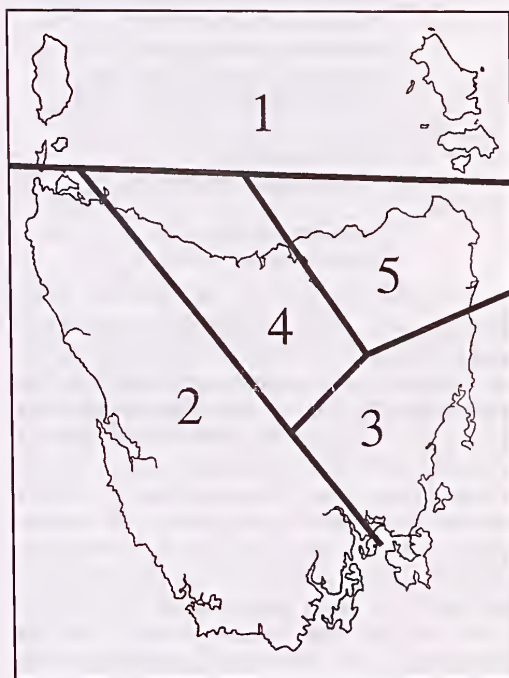

Fig.1. Map of Tasmania showing the boundaries of five faunal sub-regions.

Table 1. The distribution of the native Tasmanian land molluscs found in northeast Tasmania, in each of the five zoogeographic areas of the State (see fig. 1).

Zones:	1	2	3	4	5
Family Succineidae					
Succinea (Succinea) australis (Ferussac, 1821)	x	x	x	x	x
Family Rhytididae					
Prolesophanta dyeri (Petterd, 1879)	x	x	x	x	x
Prolesophanta nelsonensis (Brazier, 1871)	-	x	x	x	x
Tasmaphena ruga (Legrand, 1871)	x	x	x	x	x
Victaphanta lampra (Reeve, 1854)	-	-	-	x	x
Family Caryodidae					
Anoglypta launcestonensis (Reeve, 1853)	-	-	-	-	x
Caryodes dufresnii dufresnii (Leach, 1815)	x	x	x	x	x
Family Punctidae					
Laomavix collisi (Brazier, 1877)	x	x	x	x	x
Magilaoma penolensis (Cox, 1868)	x	x	x	x	x
Paralaoma caputspinulae (Reeve, 1854)	x	x	x	x	x
Trocholaoma parvissima (Legrand, 1871)	x	x	x	x	x
Family Charopidae					
Allocharopa kershawi (Petterd, 1879)	-	x	x	x	x
Dentherona (Kannaropa) subrugosa (Legrand, 1871)	x	x	-	x	x
Discocharopa vigens (Legrand, 1871)	-	x	x	x	x
Elsothera limula (Legrand, 1871)	-	-	-	x	x
Elsothera ricei (Brazier, 1871)	-	x	x	x	x
Pernagera kingstonensis (Legrand, 1871)	-	x	-	x	x
Pernagera officeri (Legrand, 1871)	x	x	x	x	x
Pernagera tamarensis (Petterd, 1879)	-	-	-	x	x
Roblinella gadensis (Petterd, 1879)	-	-	x	x	x
Stenacapha hamiltoni (Cox, 1868)	x	x	x	x	x
Thryasona diemenensis (Cox, 1868)	x	x	x	x	x
Family Cystopeltidae					
Cystopelta petterdi Tate, 1881	x	-	x	x	x
Family Helicarionidae					
Helicarion cuvieri Ferussac, 1821	x	x	x	x	x

Table 1 lists the species of native land molluscs known from within Zone 5, the Northeast of the State. For each of these species, the known distribution within each zone is listed. From this table it is seen that the native land snail fauna of the Northeast zone consists of 24 species in seven families. Of these, all species except one also occur in Zone 4 and all except six occur in Zone 3. This list is based on the taxonomic arrangement of the described species set out in Smith (1992). Further work by the author, R. Kershaw, R. Mesibov and K. Bonham suggests that there may be several undescribed species in the fauna of the Northeast zone. The one member of the land mollusc fauna of the Northeast that is found in no other part of the State is the large caryodid, *Anoglypta launcestonensis* (Reeve, 1853).

Anoglypta launcestonensis

This large (adults up to 35 mm in diameter) caryodid snail is characterized by its depressed, trochoid shape, coarse granular dorsal sculpture, pronounced keel, smooth ventral surface of dark chocolate colour with a wide, bright yellow spiral stripe. The anatomy, ecology and distribution of this species is well described by Kershaw (1988), who shows it to be largely confined to temperate rainforest within the area designated as Plomley's Island by Mesibov (1994), with a total distribution area of about 2 500 sq km. Seemingly viable populations have been found in a number of localities, including several State parks and forest reserves within the area. However, these populations are separated one from the other by areas of cleared land, areas planted with a monoculture of either

exotic or indigenous species of trees or areas of State forest. These latter are subject to harvesting and regeneration cycles in rotation with all the prescribed forestry practices associated with these activities. Thus the known populations make up a mosaic of isolated areas of unknown long-term viability. Until the more comprehensive survey of the distribution of this species was assembled by Kershaw (1988), it was thought that the species was confined to only a few localities and should be given a conservation status of 'endangered' (Smith 1983). Although the species is known from many more localities, and some of those are in parks or reserves, the conservation status of the species is still very doubtful. It is not known what size of population is needed in this large species to ensure its long-term viability. Very few juveniles are seen in field surveys. This may suggest that the species is long-lived, with a very slow replacement rate. If this is true then the species would be particularly susceptible to catastrophic events such as wildfire or local disease. For these reasons the conservation status of this species should at the very least remain 'vulnerable'.

Significance of northeast Tasmania

The native land mollusc fauna of northeast Tasmania is a subset of the fauna of the whole State. There appears to be only one species confined to this region. One other species, the rhytidid *Tasmaphena sinclairi*, is widespread over most of the rest of the State but appears to be absent from the Northeast. The area immediately to the south of Plomley's Island, Zone 3, does not support six of the 24 species found in Zone 5; whereas Zone 4, the central north region, has all the species except one found in Zone 5.

Using the mollusc fauna as an indicator, can the Northeast be considered a faunal sub-region of the State? In my opinion the answer to this question is 'Yes'. The presence of *Anoglypta launcestonensis* alone, as the representative of a genus endemic to the area, is sufficient to delineate the area as a faunal sub-region. This large, singular snail, which once appeared to have been widespread and abundant throughout the area (Hedley 1891) has not been shown to have occurred anywhere other than the Northeast. The fossil *Helix simsoniana* from Flinders Island may have been related to this genus but that is still from the northeastern part of the State (Kershaw 1988).

The snail fauna of the Northeast appears to have close affinity with the fauna found in the wet forest of the central north and to be different in several important respects from the fauna of other parts of the State.

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Post-script: Since this paper was presented, Forestry Tasmania has commissioned a distributional survey of *Anoglypta launcestonensis*. This was carried out by Kevin Bonham. He will be presenting his findings elsewhere and making a further assessment of the conservation status of this very important species.

Aquatic Microcrustacean Biogeography of Freshwater Wetlands and Coastal Dune Lakes of Northeast Tasmania

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Abstract

Disjunct population distributions of freshwater microcrustacean species in northeast Tasmania and southern Australia may be explained by Miocene and Quaternary paleoclimatic change, a concomitant change in the hydrological/limnological environment and Pleistocene existence of the peninsular land bridge between Tasmania and southeast Australia.

Introduction

Limnologically, Tasmania is rich and diverse, acclaimed by some (Tyler 1992) as a 'lakeland' containing unique and endemic microorganisms whose discovery has given some insight into evolutionary pathways and biogeographical relationships. Topographically the main island of Tasmania is mountainous and the coastal plains are generally narrow, except in the North and Northeast. Tasmania has a temperate maritime climate. There is a strong precipitation gradient decreasing west to east across the island. Average annual rainfall varies from 3 600 mm in the west to 550 mm in the east. Tasmania's diverse topography and rainfall combine to offer a wide variety of natural water bodies. Lentic waters range from highland and lowland lakes (mostly glacial in origin) to swamps and coastal dune lakes and wetlands of either a temporary and permanent nature.

The limnological character of Tasmania's inland lakes has been well studied (Buckney & Tyler 1973; Croome & Tyler 1972, 1973, 1975; Steane 1979; Bowling et al. 1986; Bowling 1988; Tyler 1992). Lentic freshwater bodies in the narrow coastal margins of Tasmania have been less thoroughly investigated than highland lakes. Significant proportions of the narrow coastal lowlands which fringe Tasmania contain extensive dune systems of calcareous or siliceous sands.

The dune lakes studied lie on the relatively extensive sandy coastal plain in the Northeast (fig. 1). Longitudinal dunes of Pleistocene siliceous sands cover approximately 350 km² in northeast Tasmania. They are a result of changes in the climatic regime within the Pleistocene. Holocene coastal parabolic dunes up to 2 km in length occur in close association with the Pleistocene dunes and have been formed by wind since the latest marine transgression of Bass Strait (Bowden 1978) separated Tasmania from the Australian mainland. The sandy plain and the dune systems form an unconfined aquifer draining the northeast Tasmanian coastal plain. In the gutters, swales and depressions between dune ridges are found the lagoons, lakes, marshes and swamps of the coastal wetlands. These form by a variety of processes, with several classification schemes proposed, based on

mode of origin (Bayly & Williams 1973; Timms 1986, 1992). Generally, however, water accumulates either from exposure of the water table, from local run-off because surrounding soils do not permit infiltration, or from both phenomena. Almost all of the lagoons are polymictic, spanning a range of nutrient states, are of variable depth and have strong seasonal trends. Most have extensive emergent macrophyte communities. Physicochemically these lagoons are similar to those in temperate parts of mainland Australia and on the Bass Strait islands, being of low to moderate salinity, high acidity, moderate to high dystrophy and a seawater ionic character dominated by Na^+ and Cl^-. The term 'coastal lagoon' can have precise meaning (Barnes 1989), though Bowling et al. (1993) and Timms (1992) referred to all types of freshwater dune lakes in Australia as coastal lagoons. The latter practice is adopted in this study of Tasmania. Many of these coastal lagoons are perched above the general water table, in dune hollows created by wind action and sealed by organically-cemented sand. Others are surface expressions of the groundwater table or shallow waterbodies impounded behind frontal dunes. Limnological information on Tasmania's lagoons has been reviewed by Bowling (1988), Bowling et al. (1993) and Walsh (1991).

This study aims to explore the relationship of the northeast Tasmanian microcrustacean fauna with that of mainland Australia and the Bass Strait Islands.

Sites, methods and materials

Study sites

All the sites are shallow, astatic coastal lagoons, of varying dystrophy, close to sea level and occupying deflation hollows located in siliceous or calcareous dunes (fig. 1). The study sites differ physiognomically, ranging from large, relatively exposed lakes to small ephemeral ponds, with depths of 4 m to <0.5 m, and from open water bodies to those dominated and covered by emergent macrophytes.
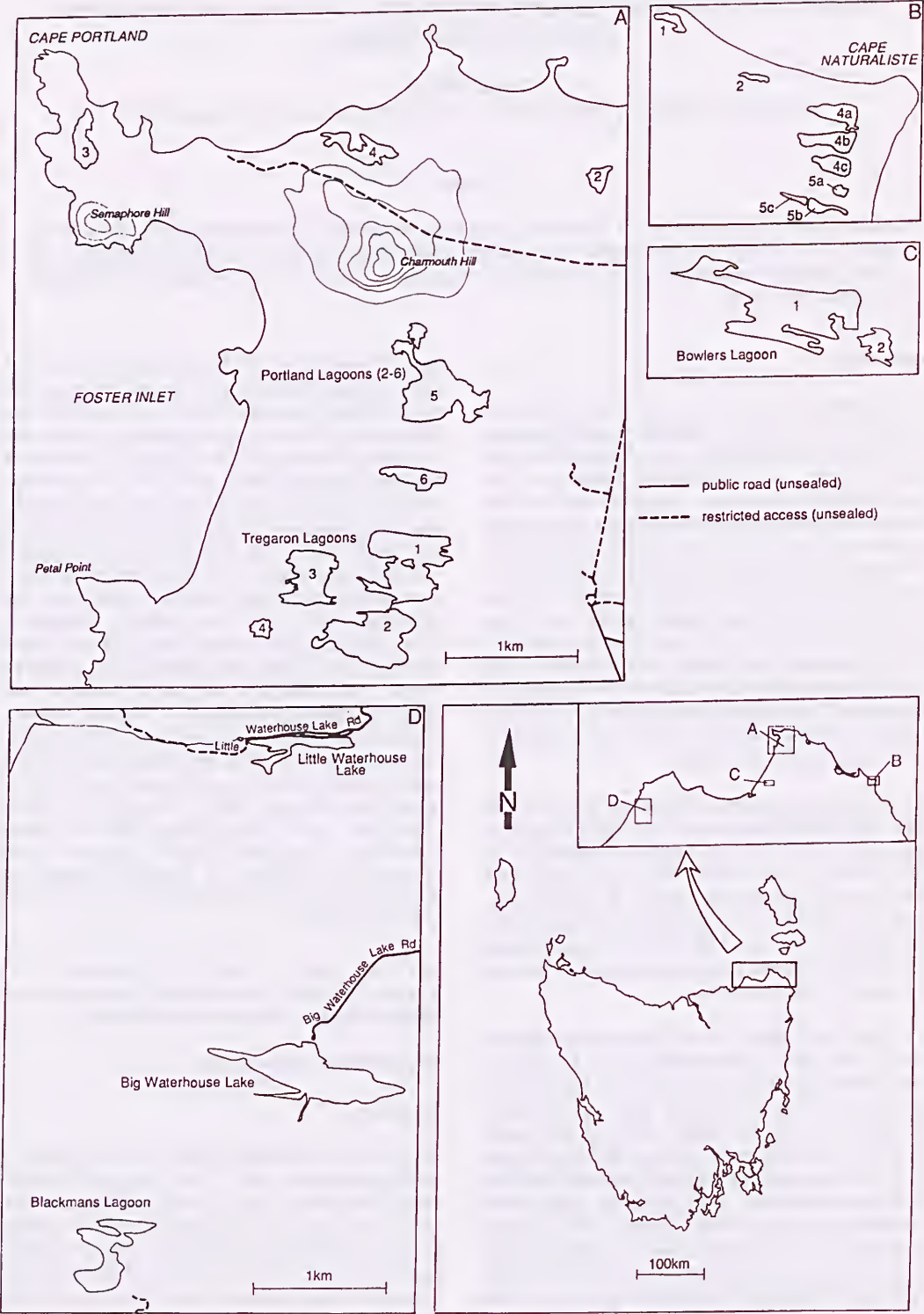
Fig. 1. Maps showing the location of northeast Tasmanian lagoons studied in this survey.

Sampling

Biological and physicochemical samples were collected at approximately three- to four-month intervals between August 1991 and September 1992 from 20 lagoons between Cape Naturaliste and the Brid River. This broad-scale approach was mainly to provide an indication of the variation among the lagoons, covering a range of lagoon types over the study area. Work is continuing on a smaller number of lagoons.

1. Biological samples

Zooplankton and phytoplankton samples were collected with 20 µm and 200 µm conical nets. All collections were preserved in 5-10% formalin pending identification. Nets were washed thoroughly before and after the sampling of each site in an effort to reduce the possibility of contamination in the samples obtained. The presence/absence of microcrustacea (identified to genera or species where possible) was recorded, with results for the two nets pooled.

Taxonomy of the Centropagidae (Crustacea: Calanoida) is based on the morphology of the male fifth pair of thoracic legs. The males, distinguished by a geniculate antenna, were transferred to a slide and mounted in polyvinyl alcohol; the male limbs were then carefully teased away from the body and taxa were identified using Bayly (1961, 1962, 1964, 1992) as reference texts. Identification of species is only possible on the basis of the form of the mature reproductive adult.

Reference texts used in the identification of the Cladocera were: Smirnov (1976) for *Ilyocryptus* spp. (now Ilyocryptidac, Smirnov 1992) and Smirnov (1992) for the Macrothricidae; Sergeev and Williams (1983, 1985) for Daphniidae and Sergeev (1990) for *Daphniopsis*, Herbert (1977) and Benzie (1988) for *Daphnia*, Flossner (1972) and Greenwood et al. (1991) for *Ceriodaphnia*, Flossner (1972) and Dumont (1983) for *Simocephalus* (in Smirnov & Timms 1983), and Korinek (in Smirnov & Timms 1983) for *Bosmina*; and Smirnov and Timms (1983), Frey (1991a, b) and Shiel 1995 for Chydoridae. Methods used in the identification of the Cladocera were those of Dodson and Frey (1991) and disarticulation after the method of Megard (1964). Identification of the Cladocera is based on the morphology of the head shield, shell valves, legs, antennules and postabdomen. Therefore, unlike the procedure for calanoids, taxonomic identification of this group was involved and time-consuming. Many of the individual specimens required clearing of tissues in concentrated KOH or HCl, and of organic debris from the body surface and from internal body chambers, to discern taxonomic features and for dissection.

2. Physicochemical measurements

Water samples were collected in acid-rinsed, opaque polyethylene bottles for laboratory analysis of major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and major anions (SO_4^{2-}, HCO_3^-, Cl^-). Samples were stored at 4°C until analysis using standard methodology (American Public Health Association 1971). Water colour (gilvin) was measured at 440 nm (g440) after Kirk (1976). Turbidity (Tn) was measured in a Hach 2100 nephelometric turbidimeter against formazin standards. Conductivity measured as K_{25} was obtained by laboratory and field electrometric measurements using a WTW LF191 electronic meter and a dip-type probe. In situ pH measurements were made with a Metroholm E558 electronic pH meter (accuracy +/- 0.1 pH unit) and a dip type probe.
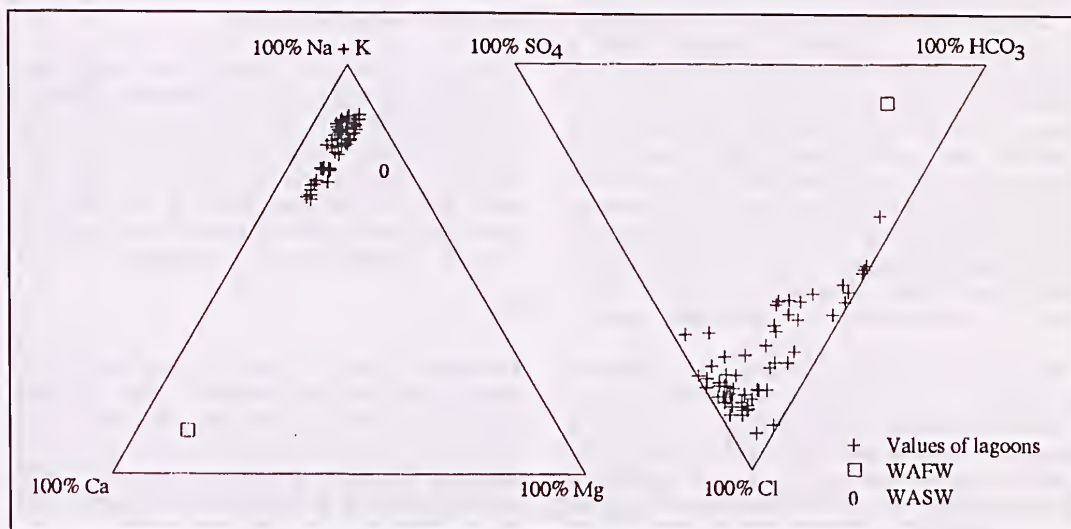

Fig. 2. Ternary diagram of major ions of northeast Tasmanian lagoons.

Results

Ionic physicochemical data are summarised in figure 2. Most of the wetlands are shallow and have extensive growths of submerged and emergent macrophytes. Seasonal changes in conductivity due to evaporative concentration were evident in the shallower wetlands. Most were fresh to slightly saline. Ionic composition was dominated by Na⁺ and Cl⁻ and with a seawater ionic character. The majority of wetlands were circum-neutral (pH 7.0) to alkaline (pH > 7.0), reflecting the influence of the calcareous sands. The wetlands were too shallow and exposed to allow thermal stratification. Most of the wetlands possessed g440 values characteristic of moderate to ultra-dystrophic water bodies and are amongst some of the highest values recorded from Tasmanian freshwater bodies (Walsh 1991). There was considerable seasonal variation in conductivity, turbidity and g440.

A total of 54 different taxa was recorded from the northeast Tasmanian lagoons (table 1). Thirteen calanoid copepod species in four genera were recorded. The cladoceran fauna was also diverse with 21 genera in five families. Generally the zooplankton community of the lagoons was dominated by *Calamoecia tasmanica tasmanica* or *Calamoecia gibbosa gibbosa*. Other species are discussed below; most records are previously unpublished localities.

Boeckella major is a large species occurring in temporary shallow pools in Victoria and Tasmania and in the highlands of New South Wales. *Boeckella propinqua propinqua* is known from northeast Tasmania and coastal New South Wales. This species, which occurs in shallow temporary waters in northeast Tasmania, has a disjunct distribution, being found in east Australia and New Zealand (North Island and far north of the South Island). A different form of this species, *Boeckella propinqua longisetosa*, which is endemic to Tasmania, occurs at higher altitudes and has a distribution restricted to west Tasmania. *Boeckella nyoraensis* may be regarded as a rare species. Prior to this study it had been collected only four times: by Searle in 1911 (Bayly 1964), Timms (1977), Baharuddin (1978) and Walsh (1991). It has not been recorded outside of Victoria and Tasmania. Its presence at Cape Naturaliste provides a link between the lagoons on Bruny Island off southeast Tasmania and a shallow humic lagoon near Portland, Victoria. In Tasmania, it occurs only in very shallow, ephemeral, acidic-humic lagoons.

Calamoecia australis is an uncommon species, restricted to Tasmania and Victoria. It has been recorded from 14 localities in Tasmania (Walsh 1991) and less than half a dozen in Victoria, most of which were of acidic-humic nature. *Calamoecia clitellata* is widely distributed across southern regions of Australia. A halobiont species, it was recorded from the lagoons of Cape Portland. This species has also been recorded from the salt pans and lunettes of the Midlands region of Tasmania.

The littoral planktonic community tends to be dominated by cladocerans, especially in those lagoons with extensive fringing submerged and exposed aquatic macrophytes. *Daphniopsis australis* and *D. pusilla* have been collected from across southern Australia including Tasmania and are an important element in the fauna of saline waters, where there are few predators or possible competitors. Their respective distribution patterns are analogous to those of *C. clitellata*, though *D. australis* has not yet been recorded from Western Australia. *D. australis* was first described from saline lakes of the Midlands region of Tasmania. These two species dominate the plankton of the shallow, saline lagoons of Cape Portland and have yet to be recorded from similar habitats on the Bass Strait islands.

Simocephalus spp. favour weedy habitats of emergent and submerged macrophytes of shallow waters. They are intolerant of acidic waters and those of dilute and low ionic content. Instead they prefer circum-neutral waters of moderate salinity but not brackish. Biogeographically, members of the genus extend along east and southern Australia, including the Bass Strait islands.

Ceriodaphnia quadrangula and *C. laticaudata* generally have an open-water, swimming existence in ponds and other small water bodies. Whilst most species of the genus favour alkaline conditions, *C. quadrangula* can tolerate a pH of 4.

Discussion

There has been only one previous study in the area concentrating upon aquatic microcrustacea (Brehm 1953) and it was one of the few that have dealt with Tasmanian aquatic microfauna. Previous studies have been piecemeal with data often extrapolated from single samples (Walsh 1991). There has been almost no work on seasonal dynamics or species assemblages.

Although Tasmania is generally more humid than continental Australia, much of east Tasmania is subject to summer drought and severe soil water deficits. In the Northeast rainfall is highly seasonal (fig. 3) with more than 80% occurring between April and October. As a result, many of the water bodies in this region are distinctly seasonal, containing water in winter months and shrinking in volume or drying up in summer.

Biogeography

Biogeography needs to be based on sound taxonomy and reliable collections. Such expertise is still not widely available in Australia (Green & Shiel 1992), and the state of taxonomy for many cladoceran groups is in some confusion. This places limitations on ecological studies and surveys such as the present one. For example, rapid changes of community dominants can occur in a matter of days or less as conditions change (Boon & Shiel 1990). Ideally, sampling more intensive than at three-month

Table 1. Occurrences of microcrustacea in northeast Tasmanian lagoons; see fig. 1 for locations. BL = Bowlers Lagoon, BLW = Big Waterhouse Lake, BMANS = Blackmans Lagoon. CN = Cape Naturaliste, CP = Cape Portland, LLW = Little Waterhouse Lake, TR = Tregaron Lagoons

	BL1	BL2	BLW	BMANS	CN1	CN2	CN4a	CN4c	CN5a	CN5b	CP2	CP3	CP4	CP5	CP6	LLW	TR1	TR2
CALANOIDA																		
Boeckella sp.	-	-	-	-	-	x	x	x	x	-	-	-	-	x	-	-	-	-
B. major	-	-	-	-	-	x	x	-	x	x	-	-	x	-	-	-	-	-
B. nyoraensis	x	-	-	-	-	-	x	-	x	x	-	-	-	-	-	-	-	x
B. propinqua	-	-	x	x	x	x	x	x	x	x	-	-	-	-	-	x	-	-
B. symmetrica	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B. triarticulata	-	-	-	x	-	-	-	-	-	-	x	-	-	x	x	-	x	x
Calamoecia australis	x	-	-	-	-	x	x	x	x	x	-	-	-	x	-	-	x	-
C. clitelata	-	-	-	-	-	-	-	-	-	-	-	x	x	x	x	-	x	x
C. gibbosa gibbosa	-	-	-	x	x	x	x	x	-	x	-	-	-	-	-	-	x	x
C. tasmanica	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-
Gladioferens pectinatus	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G. spinosus	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiboeckella searli	-	-	-	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-
CLADOCERA																		
BOSMINIDAE																		
Bosmina meridionalis	-	-	-	-	x	-	x	x	x	x	-	-	-	-	-	-	-	-
CHYDORIDAE																		
Alona sp.	-	-	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-
A. quadrangularis	-	-	-	-	-	-	x	-	-	-	-	-	-	x	-	-	-	-
Archepleuroxus baylyi	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	x	-	-
Biapertura sp.	x	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-
B. affinis	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
B. longiqua	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	x	-	-
B. rigidicaudis	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B. setigera	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Camptocercus australis	x	-	-	-	x	x	x	-	x	x	-	-	-	x	-	-	-	-
Clydoris cypretella	x	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-
Clydorus spp.	x	x	x	x	x	x	-	-	x	-	-	-	-	-	-	x	-	-
Pseudochydoris sp.	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dunhevedia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
D. crassa	-	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Ephemeroporus cf. barroisi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Graptoleberis sp.	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
Pleuroxus sp.	x	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-
Rak sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 1 (cont.)

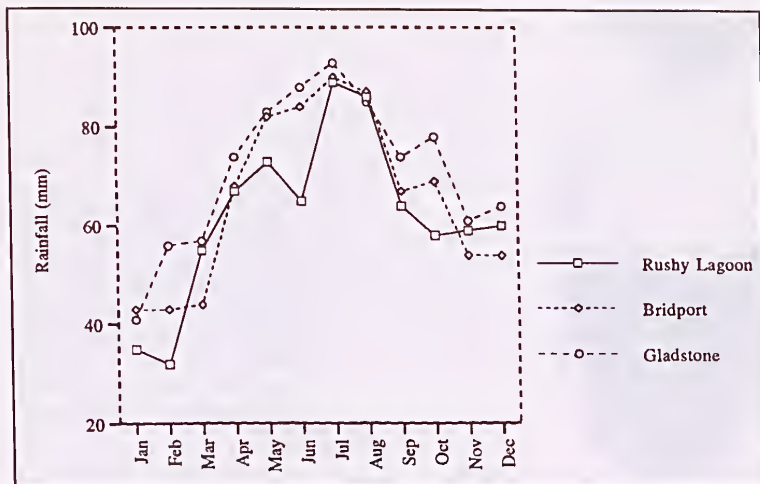|	BL1	BL2	BLW	BMANS	CN1	CN2	CN4a	CN4c	CN5a	CN5b	CP2	CP3	CP4	CP5	CP6	LLW	TR1	TR2
DAPHNIIDAE																		
Ceriodaphnia sp.	-	-	×	×	-	×	-	-	-	-	-	-	×	-	-	-	×	-
C. laticauda	-	×	×	×	-	×	-	-	-	-	-	-	×	-	-	×	-	-
C. quadrangula	-	-	-	-	×	-	-	-	-	-	-	-	-	-	-	-	-	-
Daphnia carinata	×	-	×	×	-	×	×	×	×	×	-	-	×	×	-	×	×	×
D. longicephala	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	×
Daphniopsis australis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D. pusilla	-	-	-	-	-	-	×	×	×	-	-	×	×	×	×	×	×	-
Ilyocryptus sp.	-	-	-	-	-	×	-	-	-	-	-	-	-	-	-	-	-	-
I. spinifer	-	-	-	-	×	×	×	-	×	-	-	-	-	-	-	-	-	-
Scapheloberis kingii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simocephalus sp.	×	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. expinosus	×	×	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. vetulus	×	×	×	×	×	×	-	-	-	×	-	-	-	-	-	×	-	-
MACROTHRICIDAE																		
Macrothrix sp. A	×	-	-	-	-	-	-	-	-	×	-	-	-	-	-	-	×	-
Macrothrix sp. B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	×	-
M. breviseta	×	-	-	-	-	-	-	-	-	-	×	-	-	-	-	-	×	-
M. capensis	-	-	-	-	-	-	-	-	-	-	-	-	×	-	×	-	-	-
M. carinata	×	-	-	-	-	×	-	-	-	-	-	-	-	-	-	-	-	-
M. pectinatus	-	-	-	-	-	×	-	-	-	-	-	-	×	-	-	-	-	-
M. spinosa	-	-	-	-	-	-	-	-	-	-	-	-	×	-	-	-	-	-
Neothrix armata	-	-	×	-	-	-	×	×	×	-	-	-	-	-	-	-	-	-
MOINIDAE																		
Moina australiensis	-	-	-	-	-	-	-	-	×	-	-	-	-	-	-	-	-	-

Fig. 3. Mean annual rainfall (in mm) for the period 1908-1991 using all available data from three Bureau of Meteorology stations in northeast Tasmania.

intervals would be desirable, particularly amongst the macrophyte beds. Cladocerans and copepods have short life spans, particularly during the warmer summer months, hence weekly or fortnightly sampling would more accurately describe species assemblages and population dynamics. Results of this study should therefore be considered to be broad outlines only. While the zooplankton community is sensitive to and responds to environmental changes, its use as an indicator of change (natural or man-made, long- or short-term) depends on a good systematic knowledge. Generally, the zooplankton community of the northeast Tasmanian lagoons investigated is dominated by *Calamoecia tasmanica tasmanica*, *C. gibbosa gibbosa* or *Daphniopsis*. The littoral community is dominated by chydorids, *Ceriodaphnia* and *Simocephalus*.
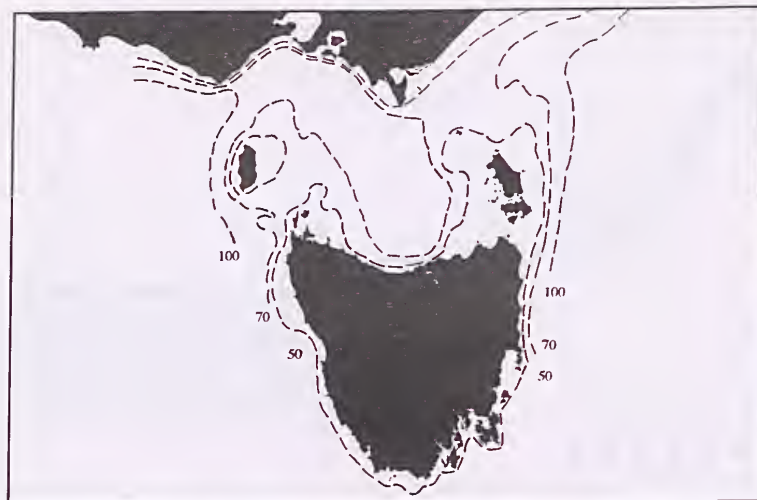
Calamoecia gibbosa was originally described from Tasmania in 1950 from Lake Dulverton. Subsequently it was recorded from east Tasmania, Bass Strait islands and the far southeast of South Australia. A different form of this species was recorded from Western Australia and given subspecific status (Bayly 1979). Bayly proposed that during more pluvial times *C. gibbosa* extended along much of the southern margin of Australia, and with the onset of aridity it became isolated in eastern and western groups. A parallel situation exists for *Calamoecia tasmanica*. This species was first described from Bruny Island, Tasmania by Smith (1909) and subsequently recorded from freshwater coastal dune lakes and acidic-humic inland waters of Tasmania, the Bass Strait Islands (Walsh 1991) and the eastern coastal regions of mainland Australia. Forms of this species occur in Western Australia and are separated subspecifically (Bayly 1979, 1984).

The subspecific divergence of *C. tasmanica* and *C. gibbosa* of east Australia from the Western Australian populations may be explained by past climate change (Bayly 1984). Some 20 my BP (20 million years ago) in the early Miocene, the southern regions of Australia experienced a humid climate that penetrated far inland (Bowler 1982). Extensive freshwater lakes would have existed where salt lakes now dominate. Bowler (1982) considered the climate sufficiently moist to allow the lakes to exist year round. Such a climate would encourage the spread of populations of freshwater calanoids across southern Australia. By the late Miocene, 6 my BP, climate change with pronounced and intense seasonal aridity through southern Australia separated the east-west continuum into two segments. By the late Pliocene, 2.5 my BP, the present climate of Australia had developed and by 1 my BP central Australia was dry (Bowler 1982). There was a period during the late Pleistocene with a return to pluvial conditions similar to those described for the early Miocene.

Bayly (1984) regards the Western Australian populations of *C. gibbosa* as relictual and a product of vicariant geographical isolation. The situation for *C. tasmanica tasmanica* in east Australia and *C. tasmanica subattenuata* in the west, while not unlike that for *C. gibbosa*, is more complex (Bayly 1979). The separation of the Tasmanian freshwater calanoid copepod populations from those of the Australian mainland may be explained similarly. Tasmania is separated from Australia by Bass Strait. The strait is approximately 250 km wide and less than 100 m deep (fig. 4). During the late Tertiary and the Pleistocene there were several Ice Ages with marked oceanic eustatic changes. In glacial and interglacial periods, sea levels were up to 200 m below and 40 m above current sea level (Galloway & Kemp 1981). During periods of lowered sea levels there would have been a land connection between Tasmania and Australia. Thus the flooding of Bass Strait would act as a vicariant event, and the exposure of the Strait would allow dispersal (Horwitz 1988)

During the last major global Ice Age, between 75 000 and c. 10 000 BP, sea levels were probably 100-120 m below present levels (Jennings 1971, Galloway & Kemp 1981). During this period Tasmania would have been the

Fig. 4. Coastline of Tasmania during the maximum of the Last Glacial. The 100 m isobath approximates the maximum lowering of sea level during this period. The area within the 100 m isobath formed a peninsular extension joining Tasmania to mainland Australia.

southernmost part of a peninsula linked to mainland Australia by a land bridge (fig. 4). The coastal northeastern portion of Tasmania would have formed the southern fringe of a large continental sandy plain of low relief, which is now under Bass Strait, with occasional granitic outcrops which are now islands of the Furneaux Group. There is some evidence to suggest that winds at this time were stronger than those of today (Bowden 1983), resulting in aeolian mobilisation of these continental sand plains and in dune formation. These would have been conditions similar to that which occur in central Australia today.

To judge from contemporary patterns, rainfall is more predictable and abundant in coastal regions. It is fair to assume that this phenomenon occurred in the Pleistocene in coastal margins of southern Australia. De Deckker (1986) suggested that a chain of lagoons along the coastal margins would have provided refuges for aquatic biota from increasing aridity. Lunettes, swamps and lagoons would have formed in the swales and gutters of the longitudinal dunes at the coastal margins of this sandy continental plain (now under Bass Strait). Such a system would have provided a corridor for the coastwise movement of aquatic biota from mainland Australia into Tasmania, and vice versa. The question of how the aquatic microbiota would have crossed the exposed Bassian Plain may be answered by passive diffusion (Pielou 1979) of resting stages by wind and waterfowl over a period of many generations. Inland, the arid conditions experienced by this continental sand plain would lead to the possible formation of saltpans and lunettes that would favour more halobiont species such as *C. clitellata, Daphniopsis australis* and *D. pusilla*.

The life history of cladocerans, and to a certain extent copepods, is shaped by their existence in shallow, ephemeral freshwaters (Hutchinson 1967). Cladocerans cope with the seasonal drying of their environment by producing resting eggs (following sexual fertilisation) which are surrounded by a thickened brood chamber

called an ephippium. These resting eggs are able to resist desiccation and lie dormant until favourable conditions return. When their habitat is next inundated the resting eggs hatch, producing females which then reproduce parthenogenetically. As almost the entire population is composed of females that have the ability to produce relatively mature offspring, there is greater potential for rapid population growth during the relatively short periods when conditions are favourable. In the wetlands of the Northeast, short generation times are induced by the high summer water temperatures. When conditions deteriorate, males are usually produced and these fertilise eggs within the female, which are then deposited in the ephippium.

Copepods rely on sexual reproduction, which leads to slower population increase than parthenogenetic reproduction, because only half of the population can produce progeny. This may explain the sporadic numerical dominance of cladocerans over copepods in the plankton assemblages observed. In copepods, eggs are carried in egg sacs attached to the urosome of the female, and hatch into small larvae known as nauplii. There are five to six naupliar stages and six copepodite stages before the adult form is assumed, the adult being the sixth copepodite stage (Hutchinson 1967). Population growth in copepods is more dependent on the survival rates of various immature stages than on egg production. Generally speaking, populations of calanoid copepods, in particular *Boeckella*, that are restricted to, or characteristic of, temporary waters have a higher mean number of eggs per clutch than do perennial species of permanent waters. Means of more than 100 eggs have been determined for *Boeckella major*.

The ease with which a taxon is able to cross a barrier is dependent upon tolerances to the environment experienced during the crossing and whether reproductive and/or physiological adaptations exist that improve chances of establishment once the barrier has been crossed. The capacity for parthenogenetic reproduction

(i.e. in cladocerans), and the ability of resting stages (eggs and cysts) to withstand periods of aridity, involving salinity changes, drought and associated wind dispersal by sediment deflation, has resulted in organisms with potential for good dispersal mechanisms. Other means of transport have included birds. Some species have been transported stuck to feathers of waterfowl (Hanski & Ranta 1983) and in their guts (Proctor 1964). However there is increasing speculation that the resting stages of cladocerans and many copepods are not necessarily as easily dispersed (Bayly & Morton 1978, Maly & Bayly 1991, Bayly 1995), i.e. the possession of resting stages does not necessarily equate with good powers of dispersal.

Together, the lagoons located in the margins of the exposed Bassian Plain provided a continuum of habitats for the freshwater fauna from Tasmania to southeast mainland Australia . With the change in climate and marine transgression of Bass Strait c. 18-10 000 BP, the populations of freshwater calanoids and cladocerans were separated into now-disjunct distributions with the southern Australian mainland fauna, that of Bass Strait Islands and that of northeast Tasmania.

The pronounced precipitation gradient currently decreasing west to east across Tasmania is due to orographic rainfall from moist westerly air streams intercepted by the western highlands. Bowden (1983) and Colhoun (1978) argued that when sea level was lower than that of today, the West Coast ranges, due to their increased elevation relative to sea level, would have increased the precipitation gradient across Tasmania. This, coupled with increased continentality due to the exposure of Bass Strait, would have increased the aridity of northeast and east Tasmania, as this would have removed the source of moisture for the northwesterly circulation patterns whose winds today bring seasonal and occasional rains to northeast Tasmania. In addition, intense low-pressure systems that currently move eastwards through Bass Strait and also bring moisture to northeast Tasmania would have been similarly affected (Bowden 1983). The increased aridity and pronounced seasonality in rains of east Tasmania as a whole during this period of the Pleistocene would be reflected in the increased ephemerality, salinity and astaticity of the coastal freshwater dune lakes and lagoons, and in the inland shallow wetlands, swamps and lakes of east Tasmania during this period. All of this would have favoured the spread of halobiont species and those with lifecycles adapted to temporary waters. It is of interest that today in the lowland lakes (both coastal and inland) of east Tasmania the cladoceran and calanoid copepod fauna is dominated by species that possess strong seasonality in their respective life histories and possess life-cycle strategies to cope with seasonal temporary waters.

Conclusion

The periodic flooding of Bass Strait as sea level rose may have acted as a vicariant event, and the periodic exposure of the Bassian Plain may have allowed passive dispersal (Horwitz 1988) by diffusion of resting stages over a period of many generations. Given current population distributions and the relative abundance of *B. nyoraensis*, *C. gibbosa* and *C. australis* in Tasmania relative to mainland southern Australia, the following questions arise:

- Did these species spread from Tasmania to the southeastern region of mainland Australia, with C. *gibbosa* then extending from there to Western Australia?
- Did these species and *C. tasmanica tasmanica* extend from southeast mainland Australia into Tasmania via the Bass Strait landbridge?

Based on the prevalence of *C. gibbosa* in Tasmania and the paucity of distribution records for southern Australia it is more likely that first option is true for this species. Conversely, due to the distribution of *C. tasmanica* up the eastern seaboard and across southern Australia, this species is felt to have extended across from the mainland. Similarly, the most likely scenario for the halobiont species of *Daphniopsis* and *C. clitellata* is that these also came across from southeast mainland Australia into Tasmania via the Bass Strait landbridge.

It is open to conjecture when the above species appeared in Tasmania. These species are widely distributed over their respective ranges from Tasmania to southern Australia. The land connection between Tasmania and the mainland has been broken and restored on numerous occasions since the Miocene. There have been up to nine glacial-interglacial episodes in the Quaternary with periods of low sea levels. The inundation of Bass Strait would have divided the above fauna into two vicariant populations. Exposure of Bass Strait would re-establish contact allowing gene flow between the two previously isolated populations. Successive appearances and disappearances of barriers (i.e. vicariant events) may lead to the concentration of numbers of species in the centre of the common range. In some cases, however, as a result of local extinctions, the greatest number of species occur in some peripheral areas (Banarescu 1990). This may explain the high microcrustacean species diversity for the northeast Tasmanian lagoons and for the calanoid copepod fauna for Tasmania as a whole, compared to mainland Australia.

The lagoons of northeast Tasmania, limnologically speaking, provide a good subset of coastal freshwater body types in Tasmania. These lagoons are rich in diversity with biogeographical affinities to south and east Australia and Western Australia.

Acknowledgements

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